

CERES Angular Distribution Model Working Group Report



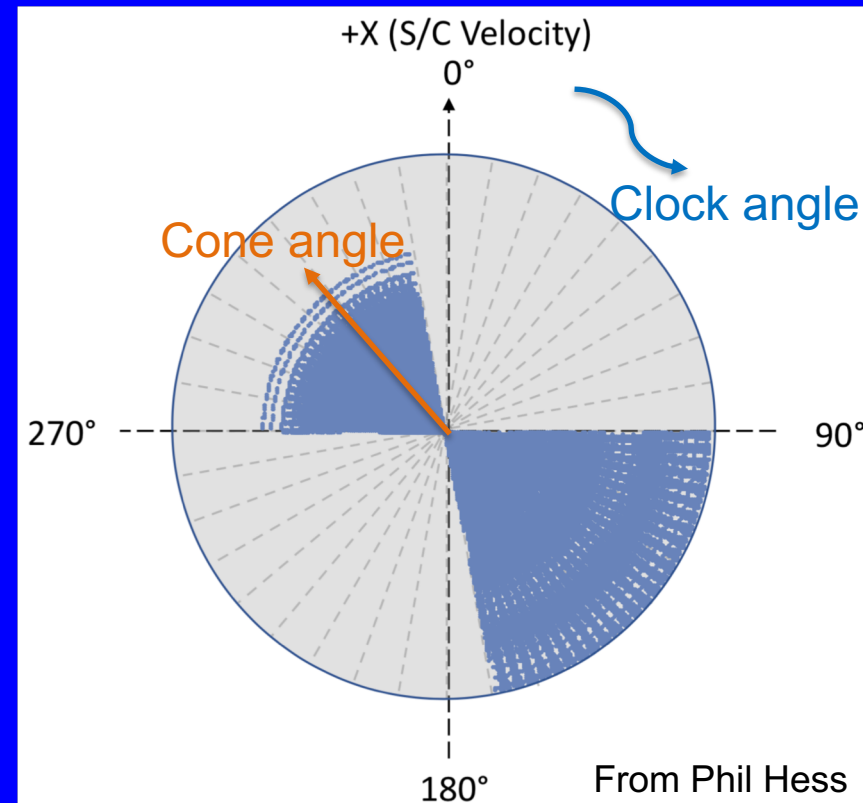
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SSAI, Hampton VA



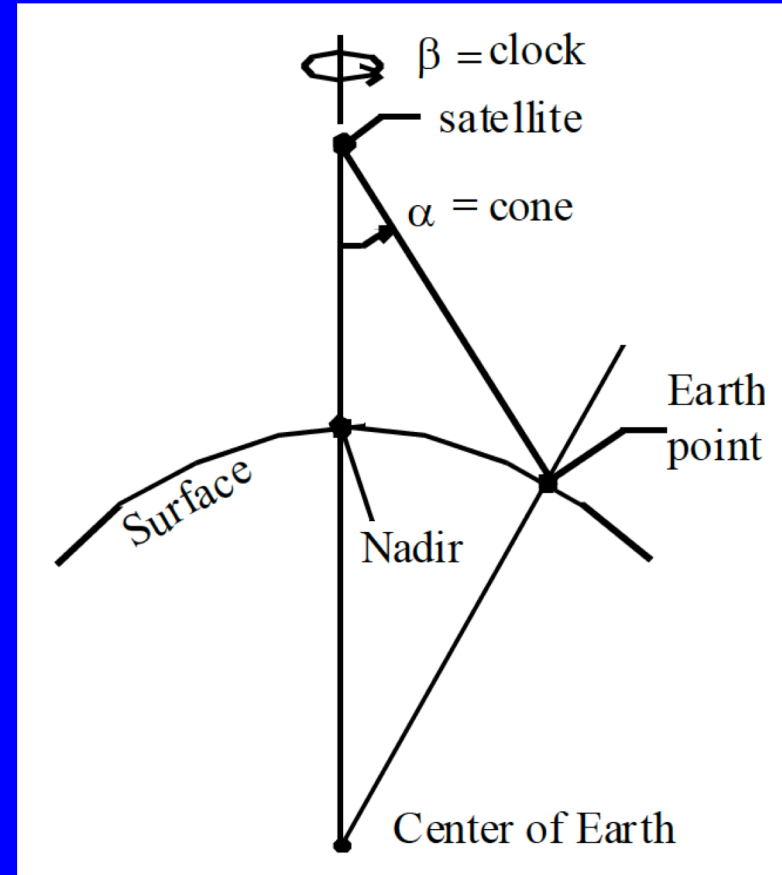
Placing NPP in rotating azimuth plane scan (RAPS) mode to collect data for ADM development

- Lessons learned from Terra/Aqua show that full RAPS mode accelerates the detector degradation;
- To avoid the degradation, NPP can not be placed in the full RAPS mode;
- Restricted azimuth and limited Sun exposure scan mode was proposed:
 - For solar beta angle $< 24^\circ$
 - Clock angle between 90° - 169° , and cone angle between 0° - 64°
 - Clock angle between 270° - 349° , and cone angle between 0° - 38° .
 - For solar beta angle $\geq 24^\circ$
 - Clock angle between 90° - 180° , and cone angle between 0° - 64°
 - Clock angle between 270° - 360° , and cone angle between 0° - 38° .



Cone and clock angle

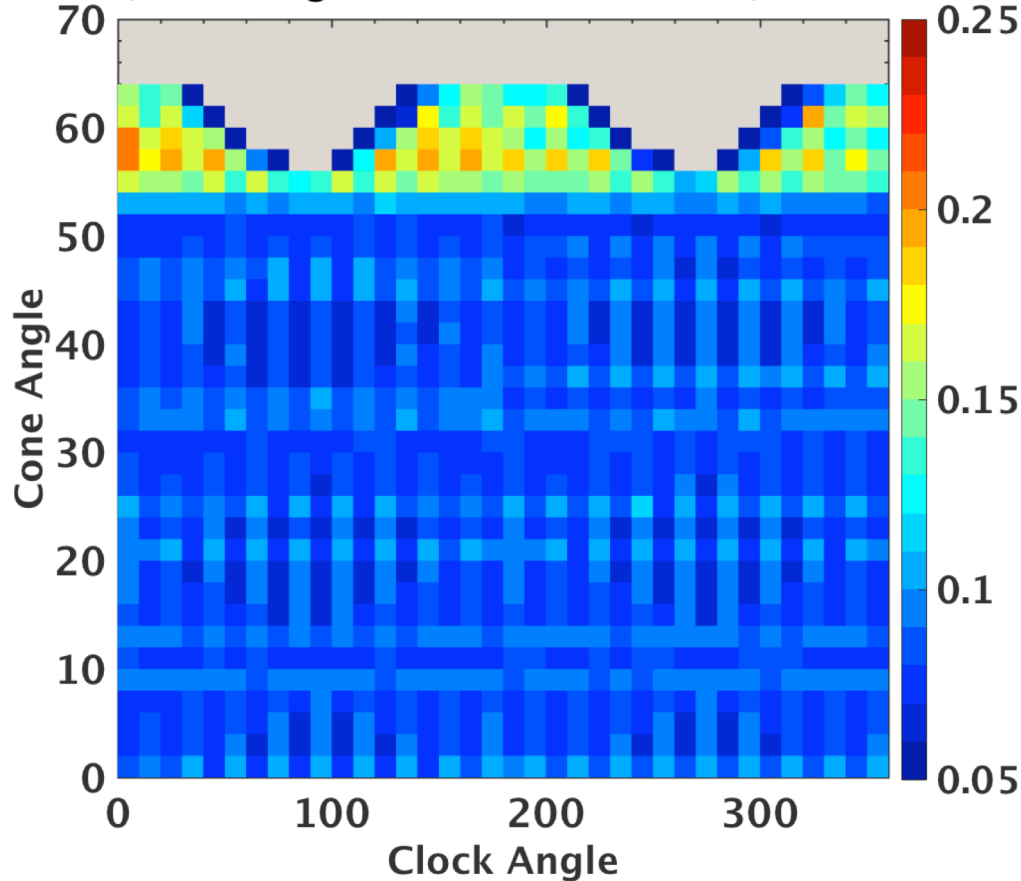
- The cone angle is the angle between a vector from the satellite to the center of the Earth and the instrument view vector from the satellite to the Earth point (ranges from 0° to 90°)
- The clock angle is the azimuth angle of the instrument view vector from the satellite to the Earth point relative to the inertial velocity vector (ranges from 0° to 360°)
- The clock angle and the cone angle define the direction of the instrument view vector to the Earth point.



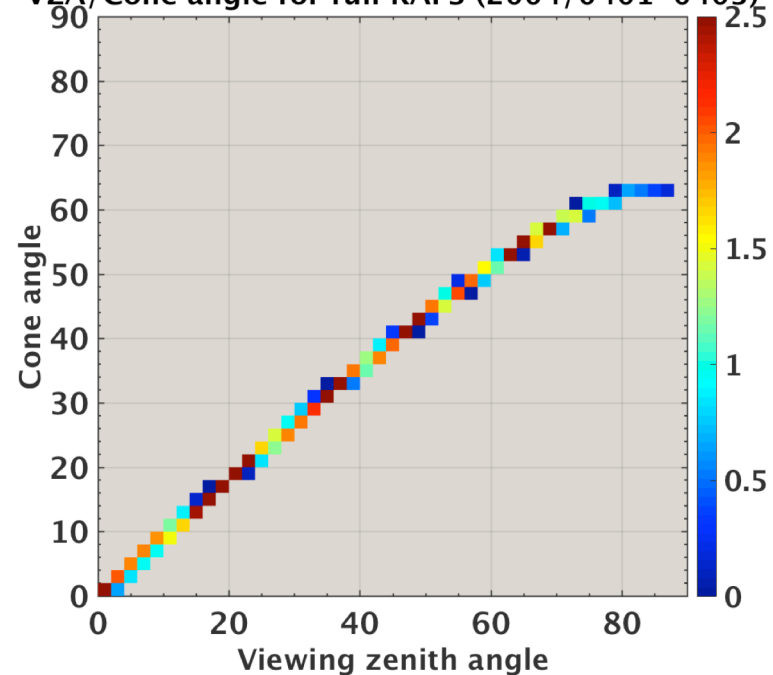
From SSF Collection Document

Relationship between viewing zenith angle and cone angle, between relative azimuth angle and clock angle for full RAPS

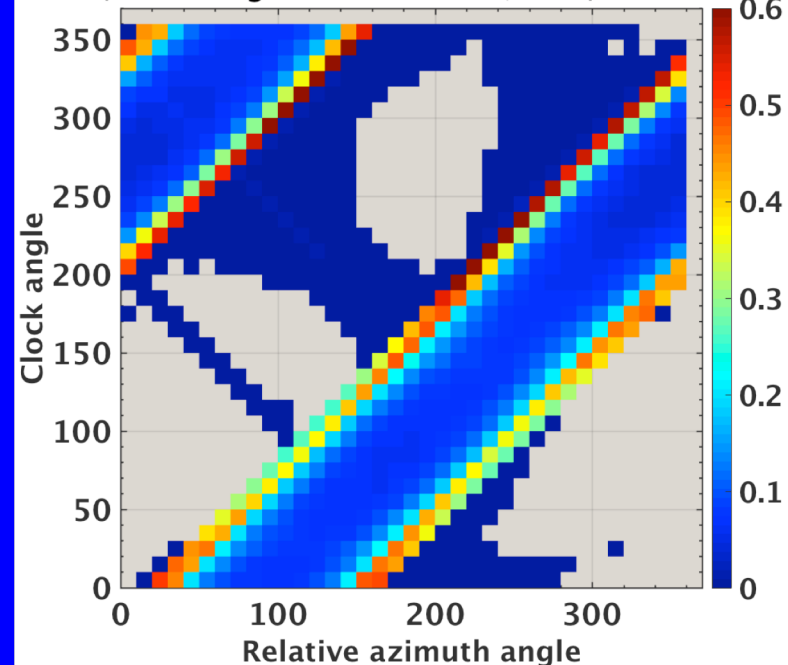
Clock/Cone angle for full RAPS (2004/0401-0403)



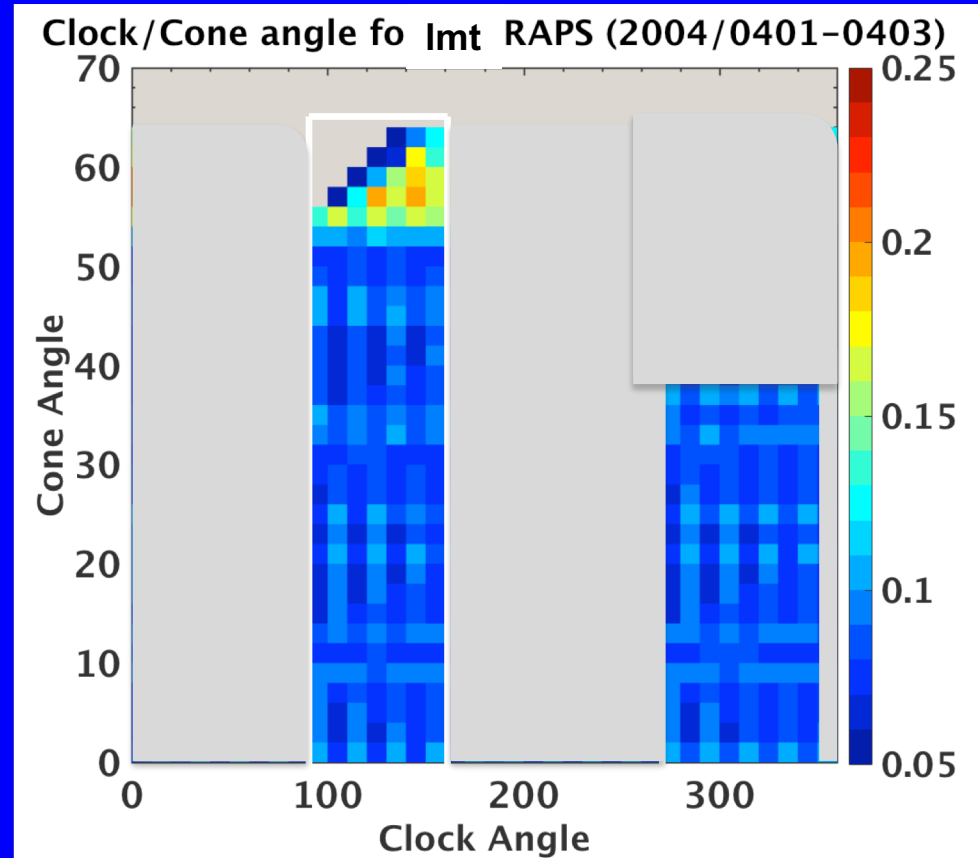
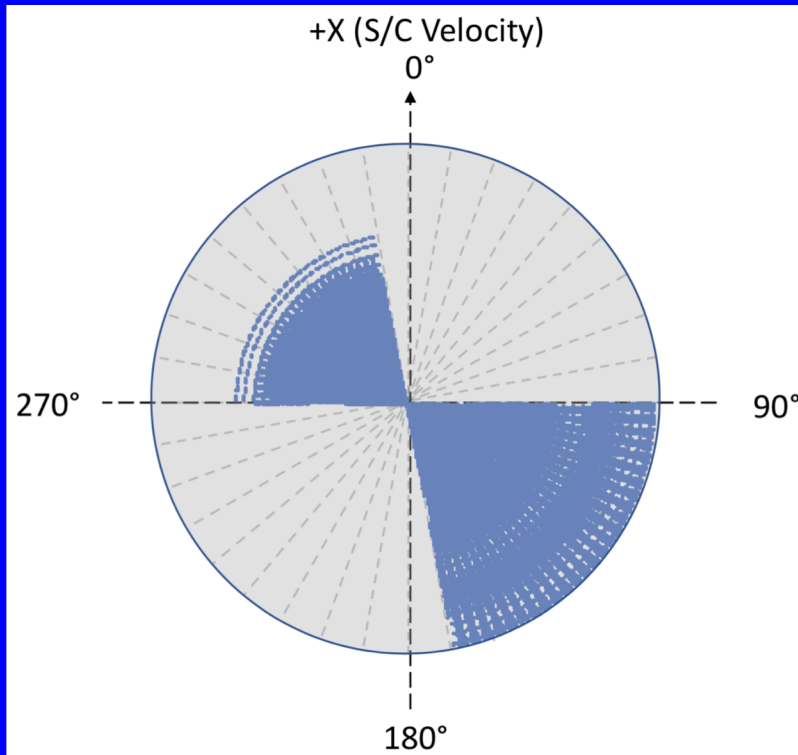
VZA/Cone angle for full RAPS (2004/0401-0403)



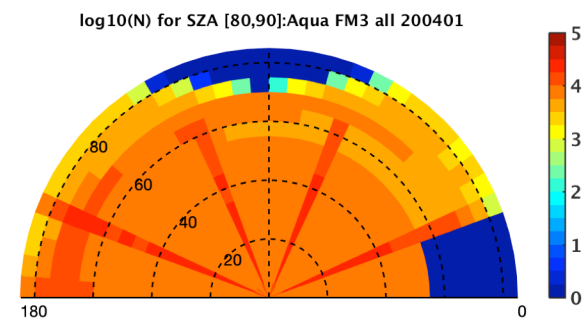
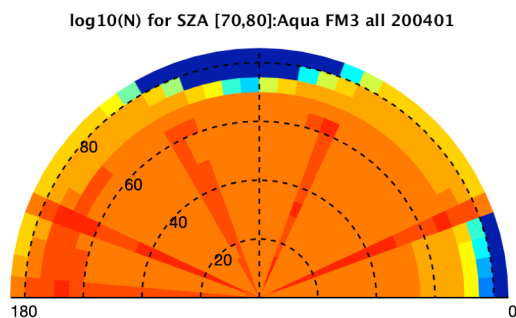
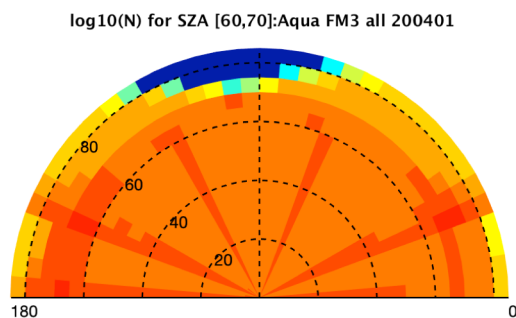
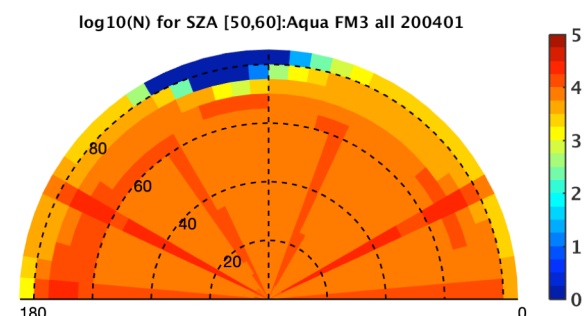
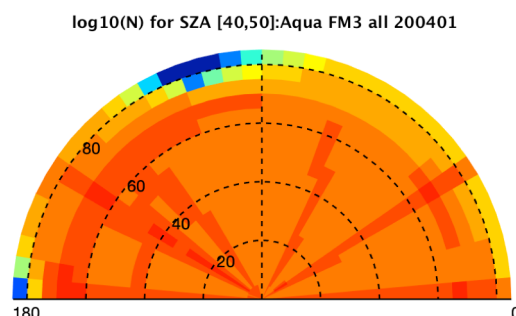
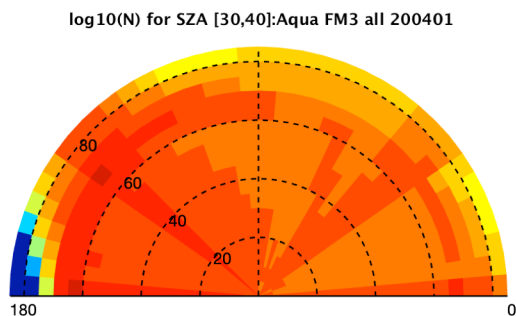
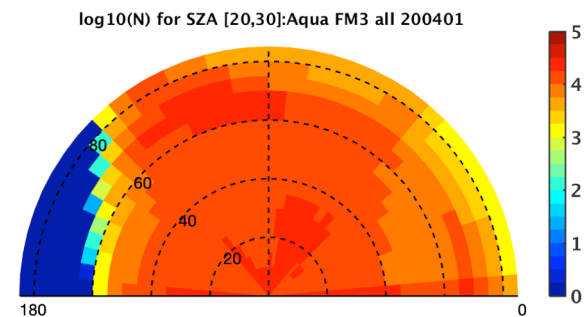
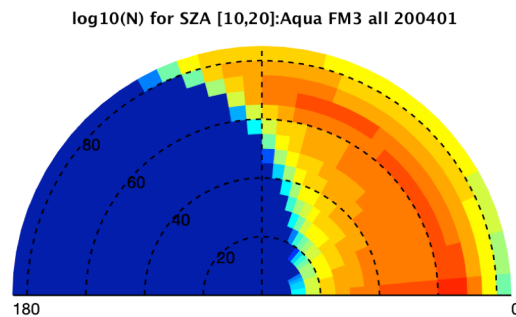
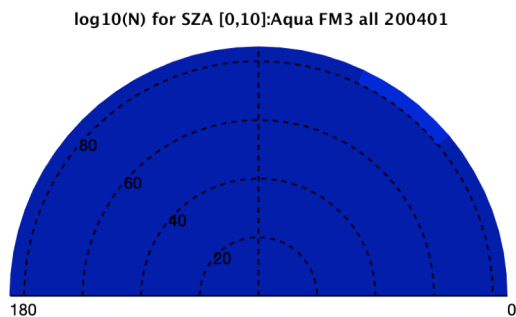
RAA/Clock angle for full RAPS (2004/0401-0403)



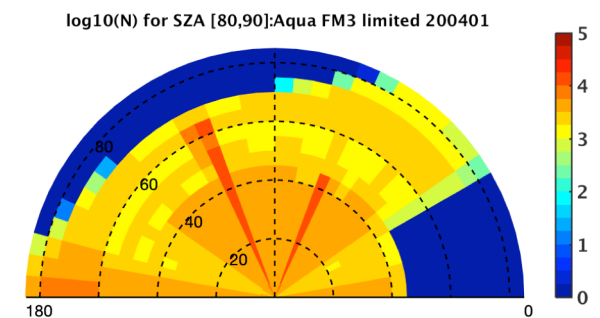
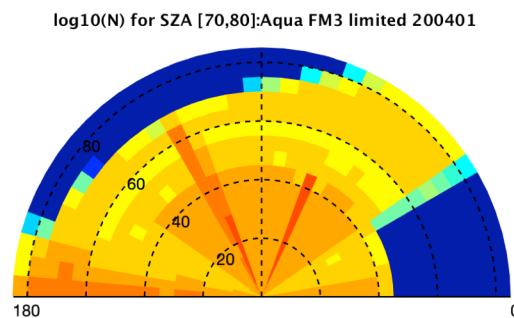
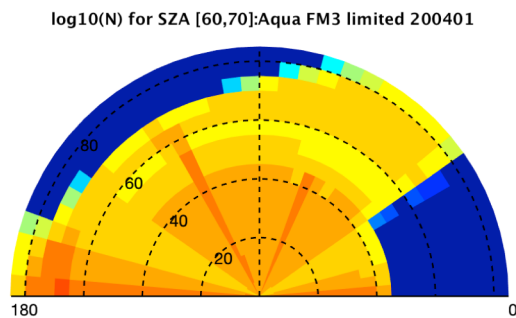
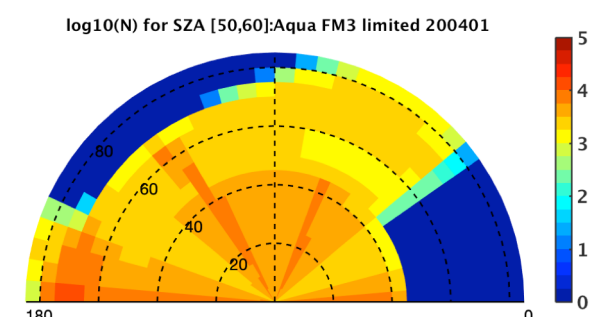
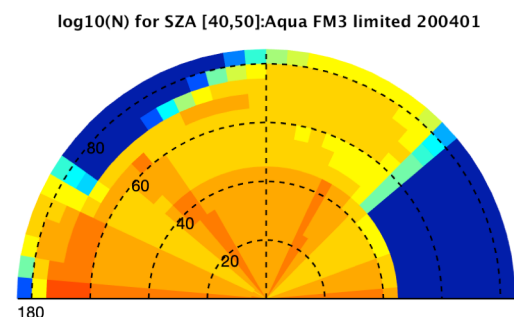
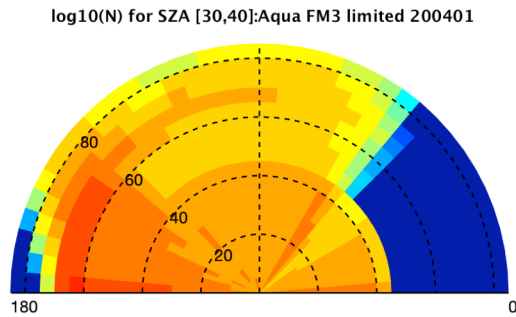
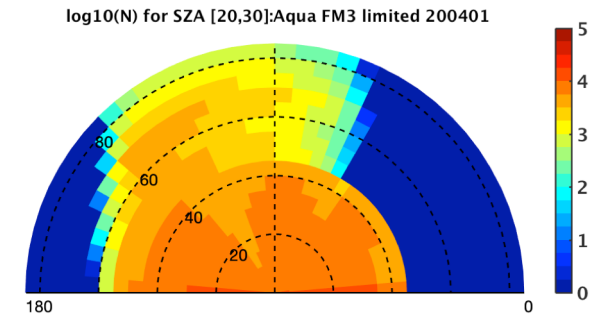
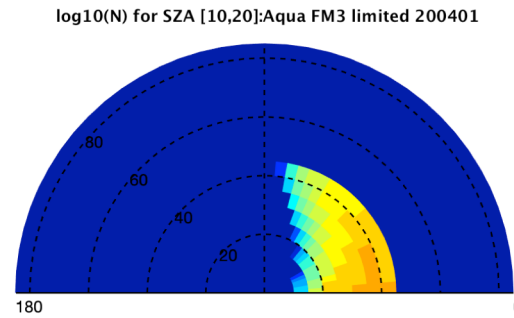
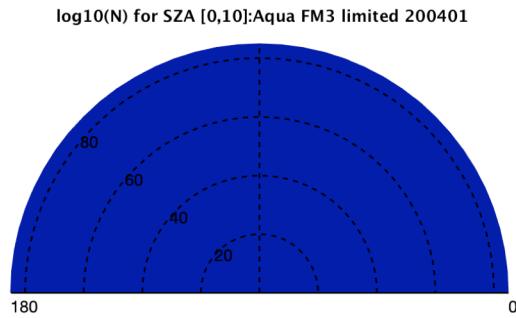
Limited Sun exposure only sample ~ 1/3 of the full RAPS footprints



Angular coverage of full RAPS mode for global all-sky: 200401



Angular coverage of limited RAPS mode for global all-sky: 200401



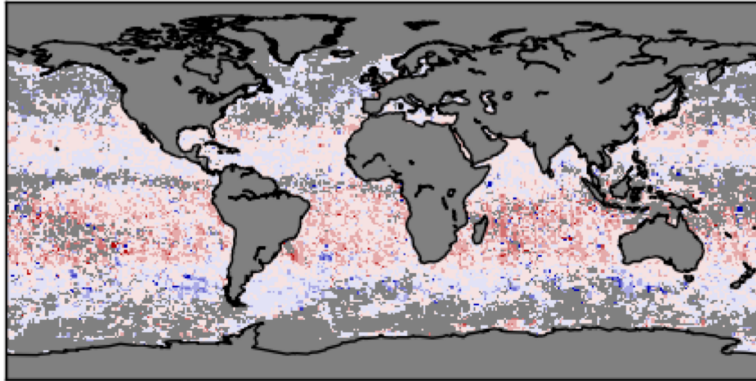
Assessing the effects of using limited RAPS on ADMs and on flux

- Construct two sets of ADMs using same code and same input files (2.5 years of RAPS and 2.5 years of cross track data)
 - One ADMs use the full RAPS
 - The other use the limited RAPS
- Use these two sets of ADMs to invert fluxes: $F = \pi I / R$
- Examine the difference between flux inverted from limited RAPS ADMs and from full RAPS ADMs: $\Delta F = F(\text{limited ADMs}) - F(\text{full ADMs})$

SW flux difference over clear ocean

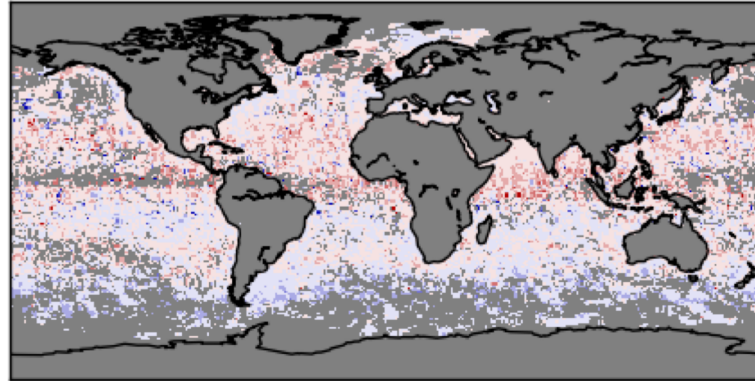
201001

$\Delta F = 0.21(\text{w/m}^2)$

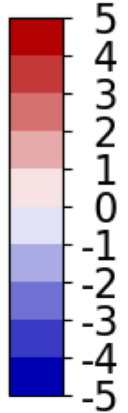


201004

$\Delta F = 0.14(\text{w/m}^2)$

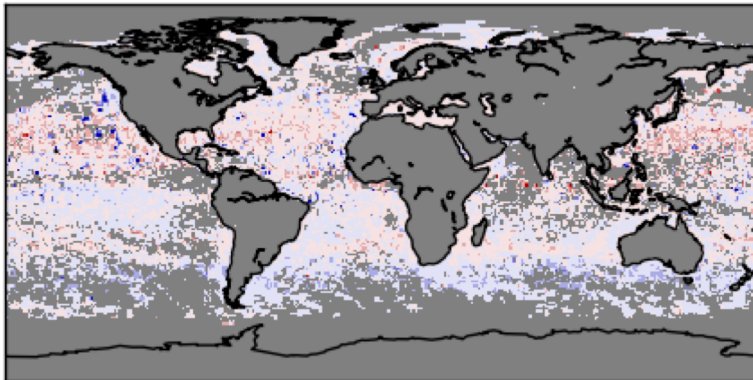


Wm^{-2}



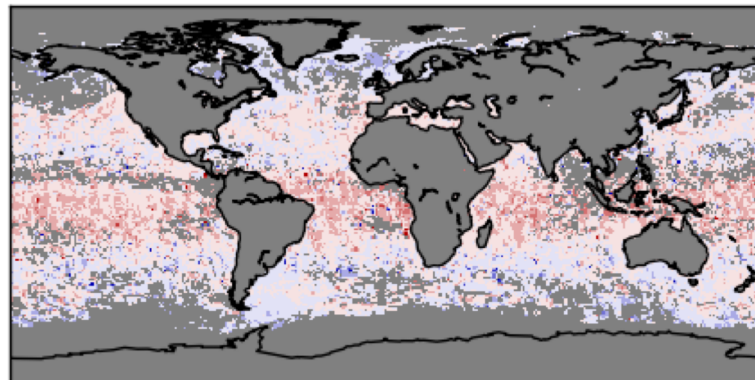
201007

$\Delta F = 0.02(\text{w/m}^2)$

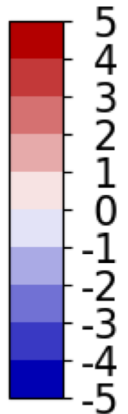


201010

$\Delta F = 0.24(\text{w/m}^2)$



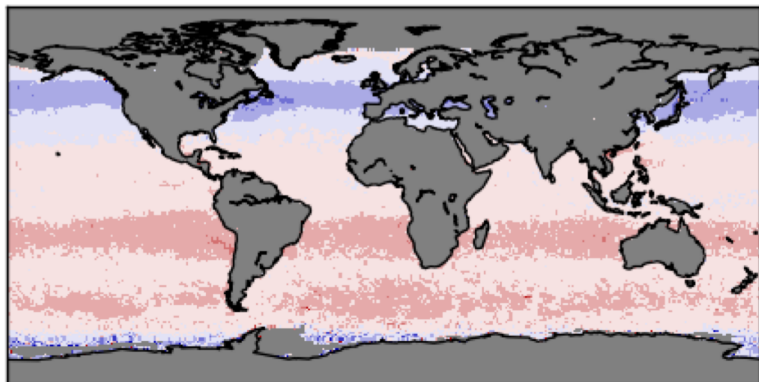
Wm^{-2}



SW flux difference over cloudy ocean

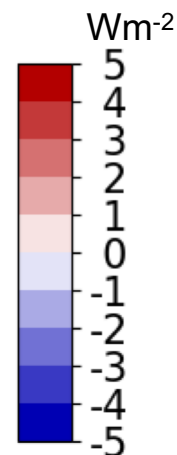
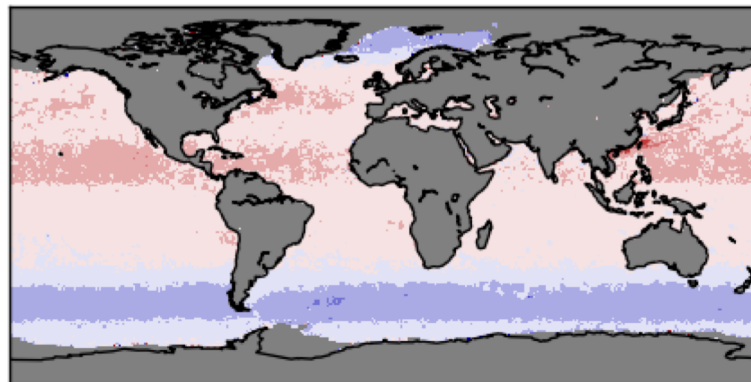
201001

$\Delta F = 0.39(\text{w/m}^2)$



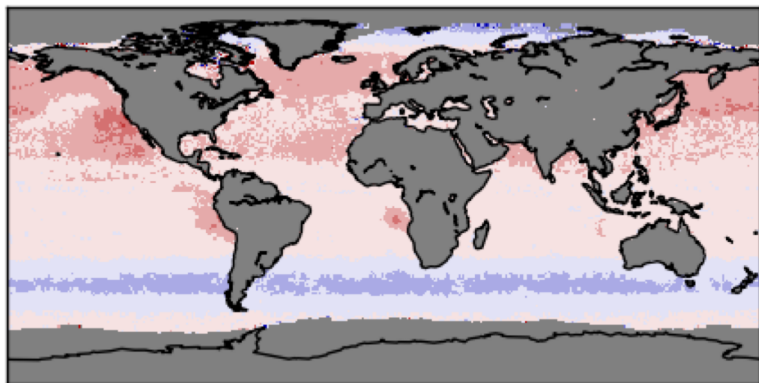
201004

$\Delta F = 0.08(\text{w/m}^2)$



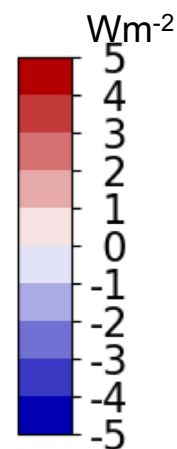
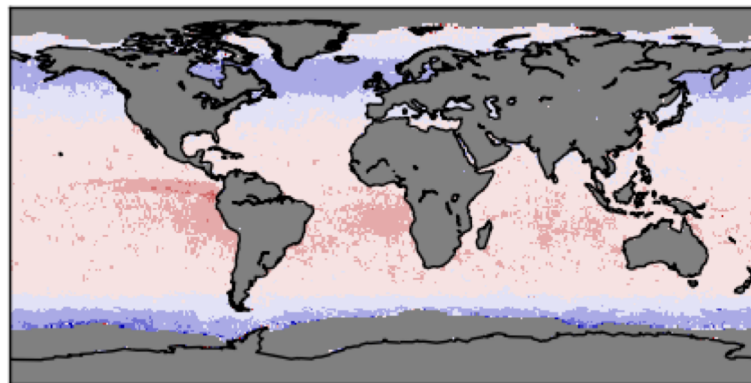
201007

$\Delta F = 0.30(\text{w/m}^2)$

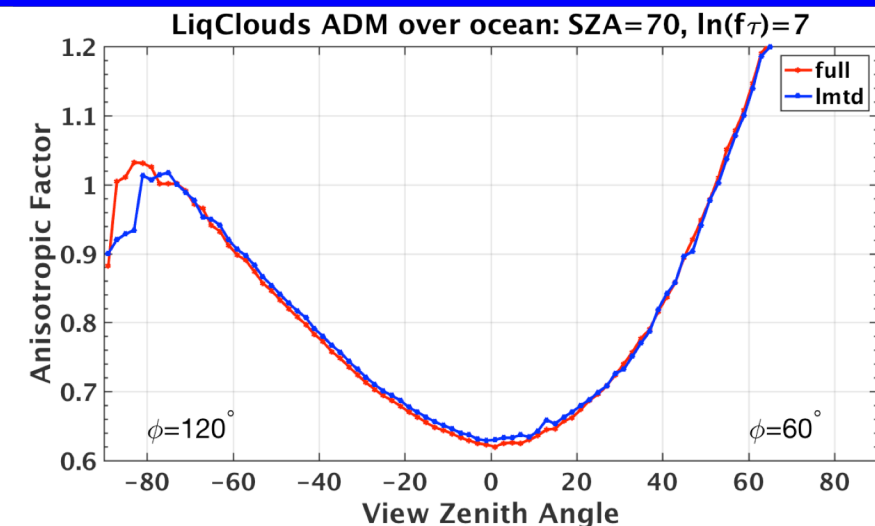
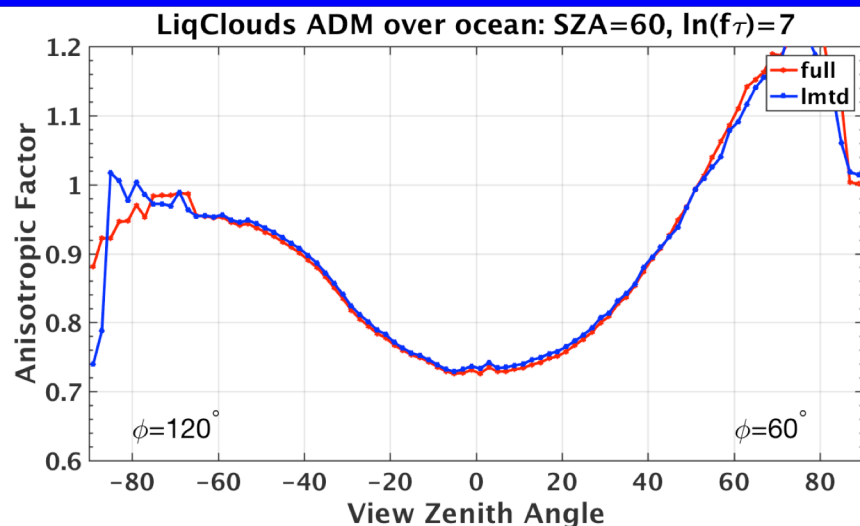
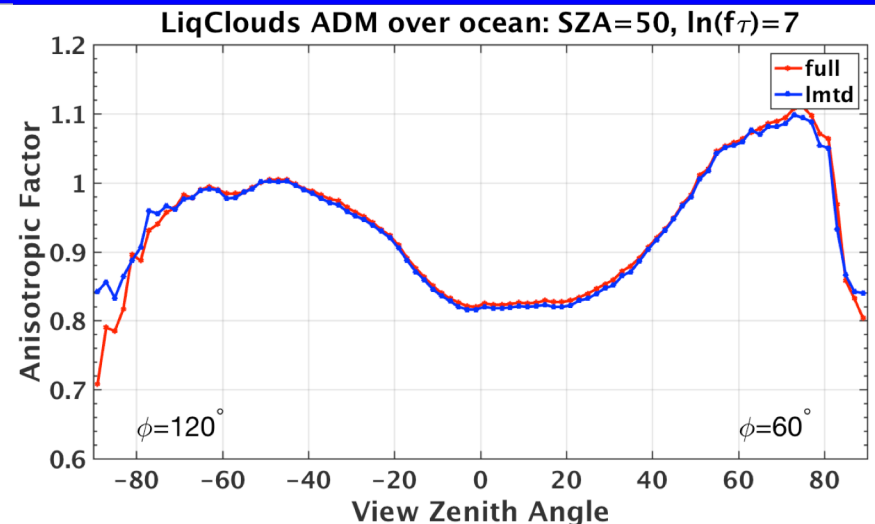
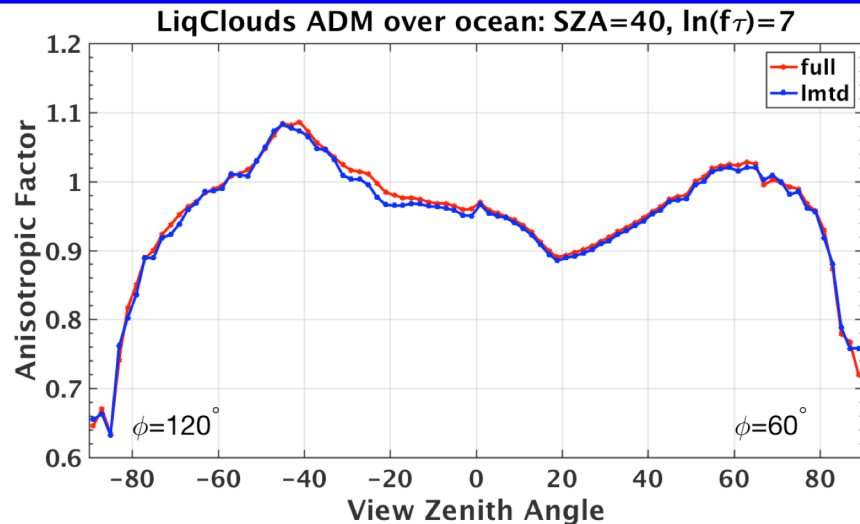


201010

$\Delta F = 0.15(\text{w/m}^2)$



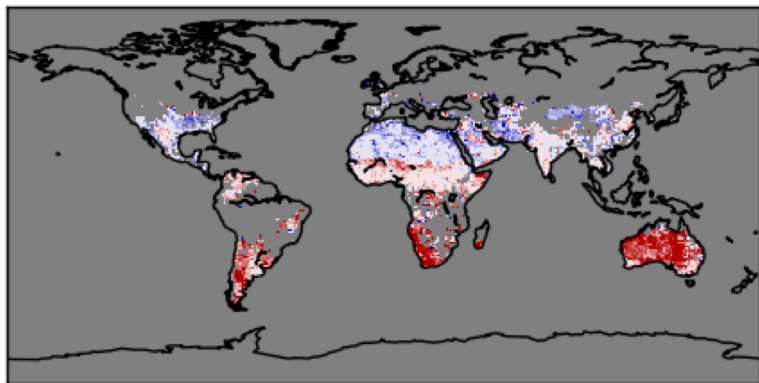
SW anisotropic factor comparison over cloudy ocean



SW flux difference over clear land

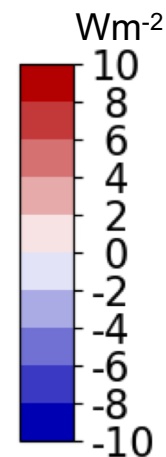
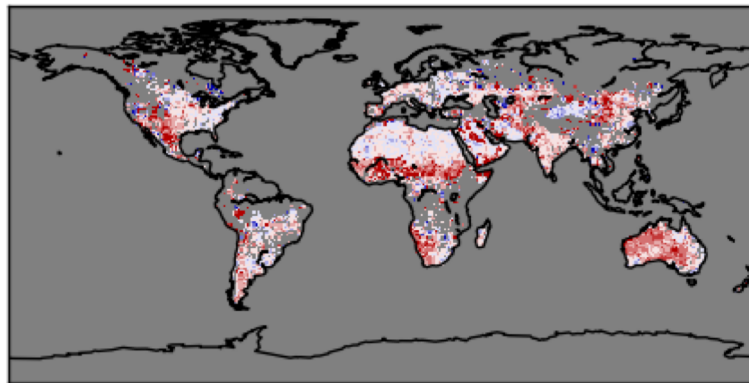
201001

$\Delta F = 1.43(\text{w/m}^2)$



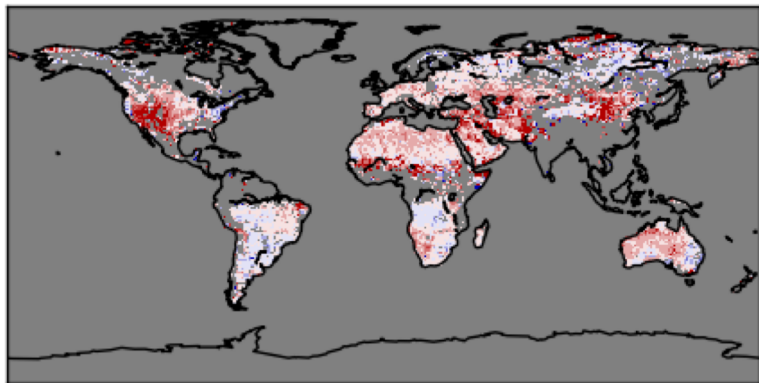
201004

$\Delta F = 2.08(\text{w/m}^2)$



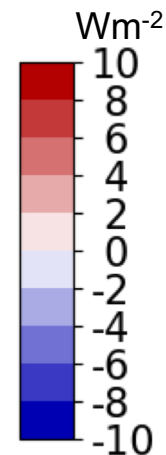
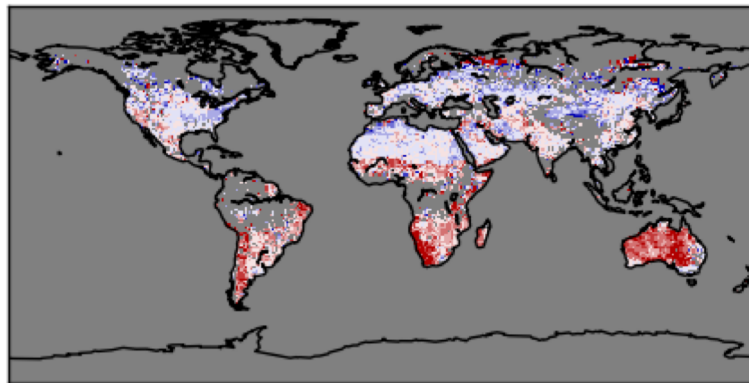
201007

$\Delta F = 2.24(\text{w/m}^2)$



201010

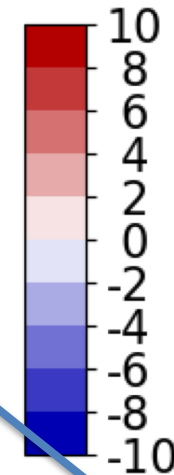
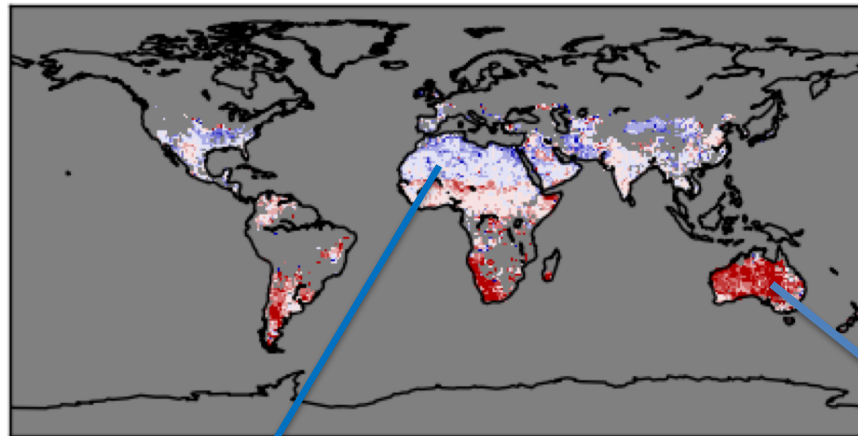
$\Delta F = 0.80(\text{w/m}^2)$



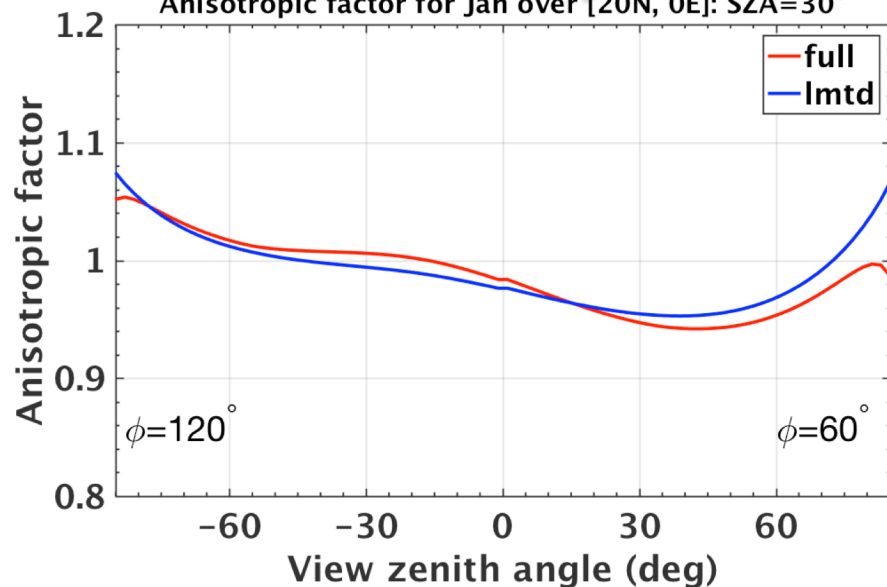
SW Anisotropic factor comparison over clear land

201001

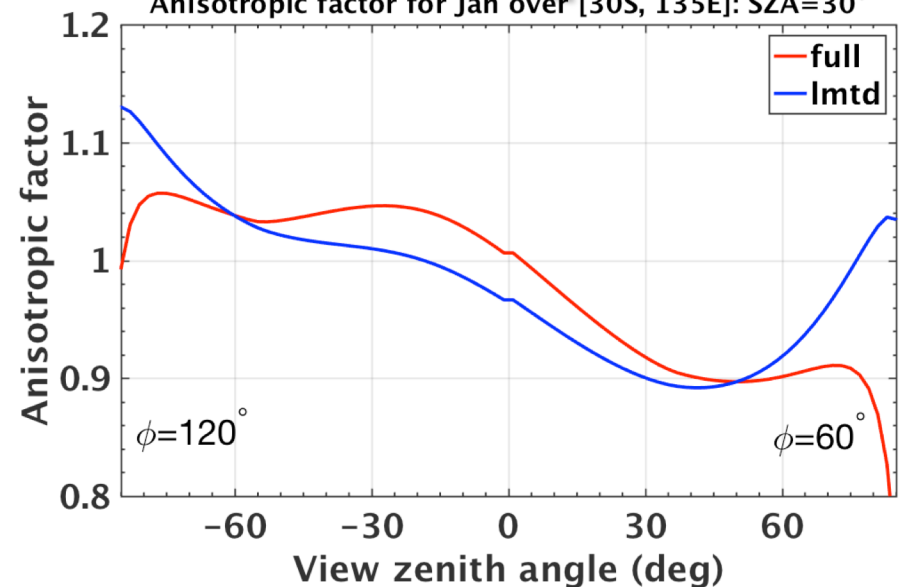
$$\Delta F = 1.43(\text{w/m}^2)$$



Anisotropic factor for Jan over [20N, 0E]: SZA=30°



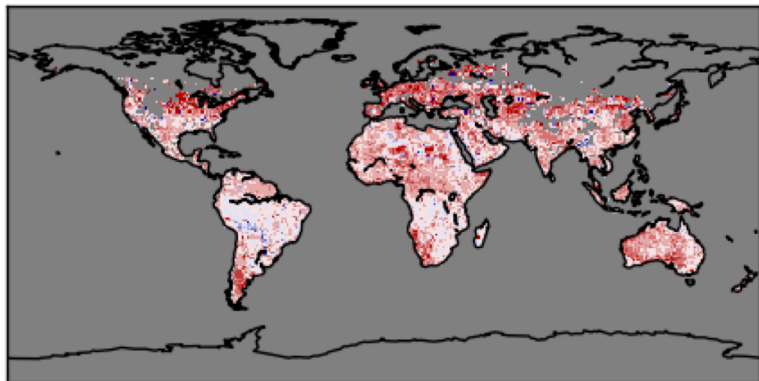
Anisotropic factor for Jan over [30S, 135E]: SZA=30°



SW flux difference over cloudy land

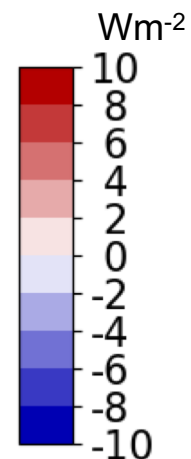
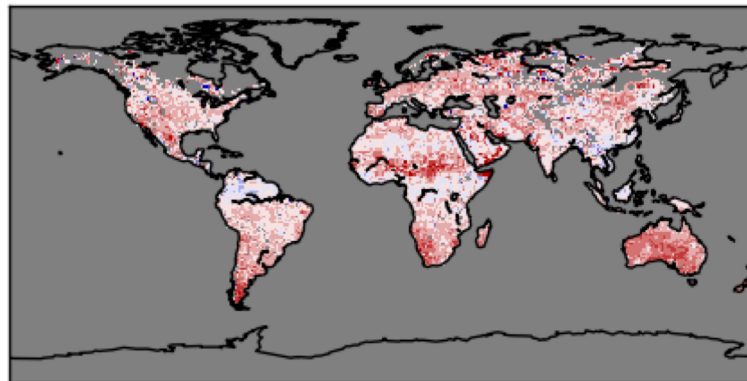
201001

$\Delta F = 2.67(\text{w/m}^2)$



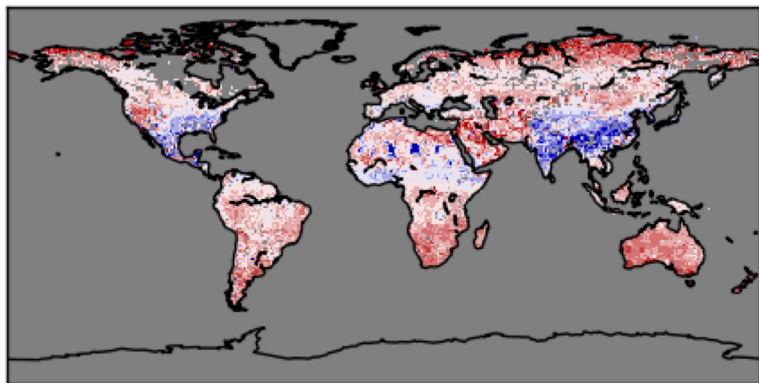
201004

$\Delta F = 2.11(\text{w/m}^2)$



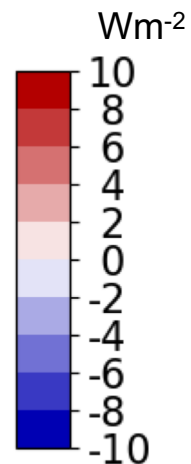
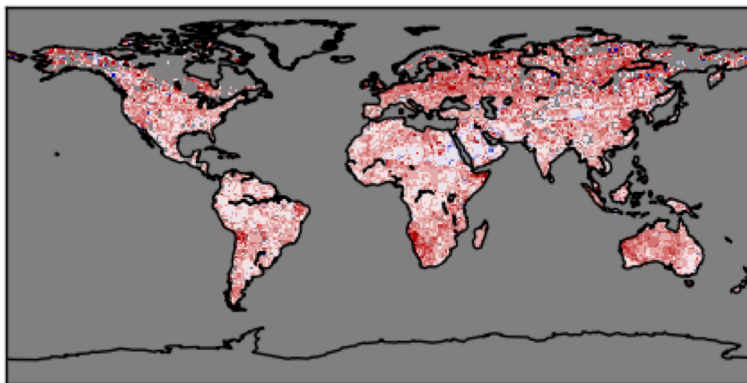
201007

$\Delta F = 1.59(\text{w/m}^2)$

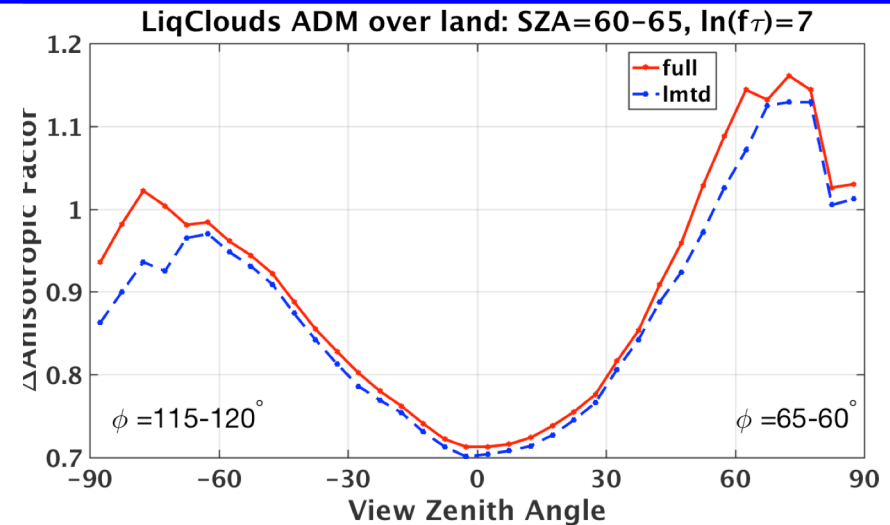
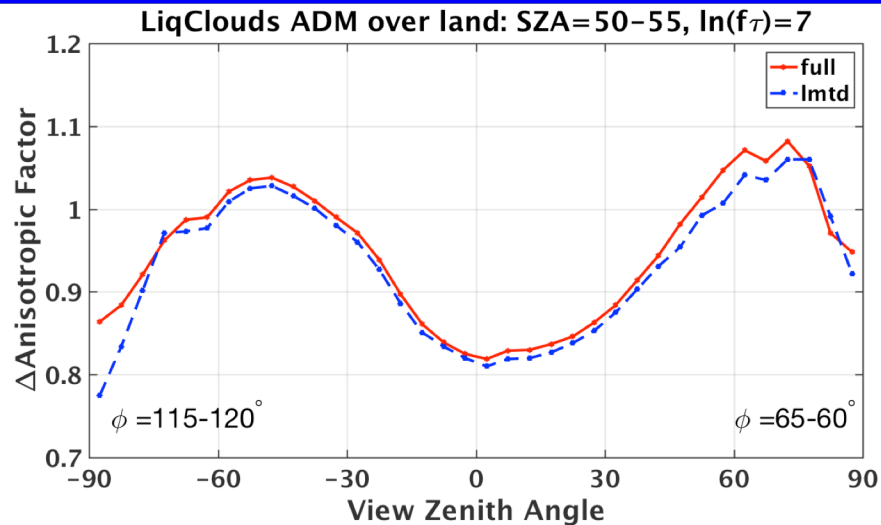
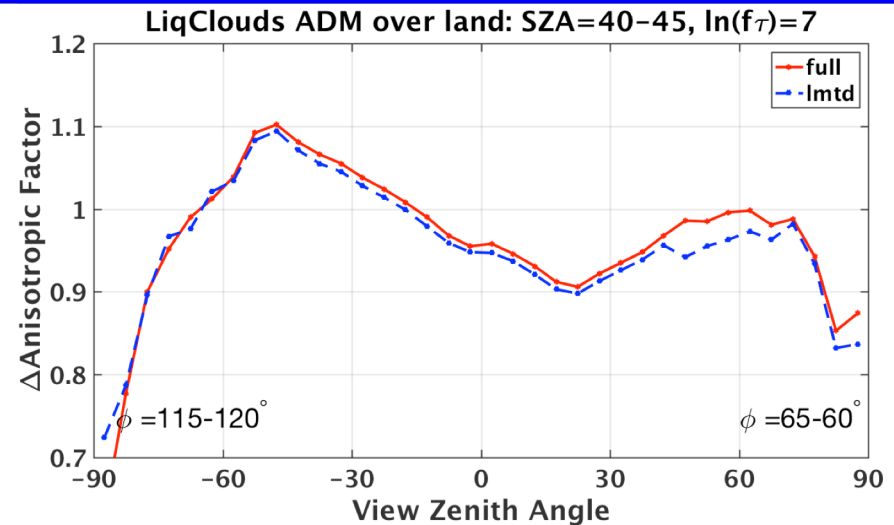
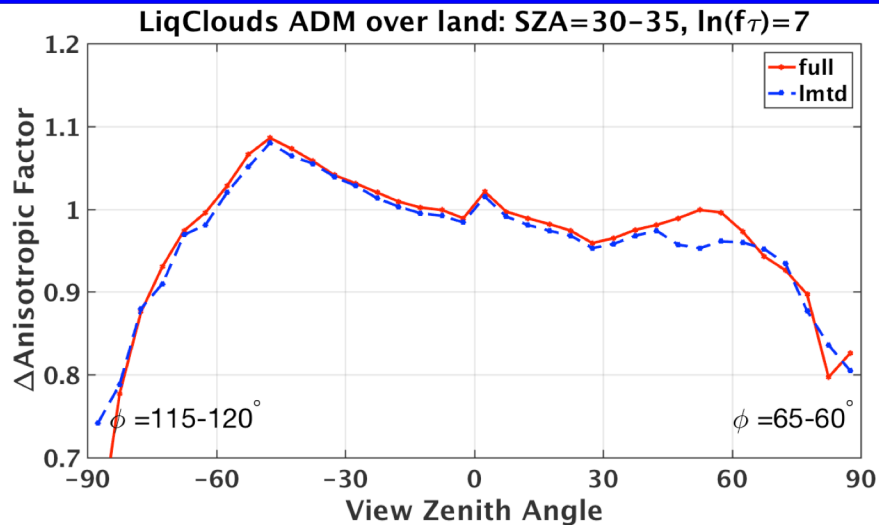


201010

$\Delta F = 3.12(\text{w/m}^2)$

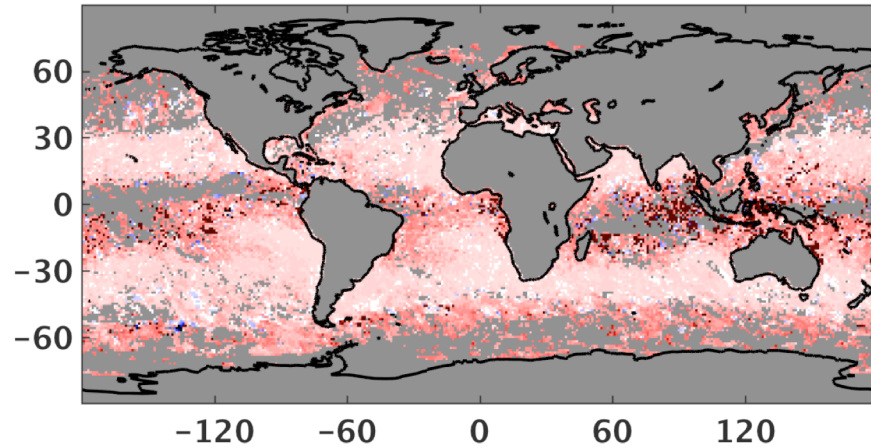


SW anisotropic factor comparison over cloudy land

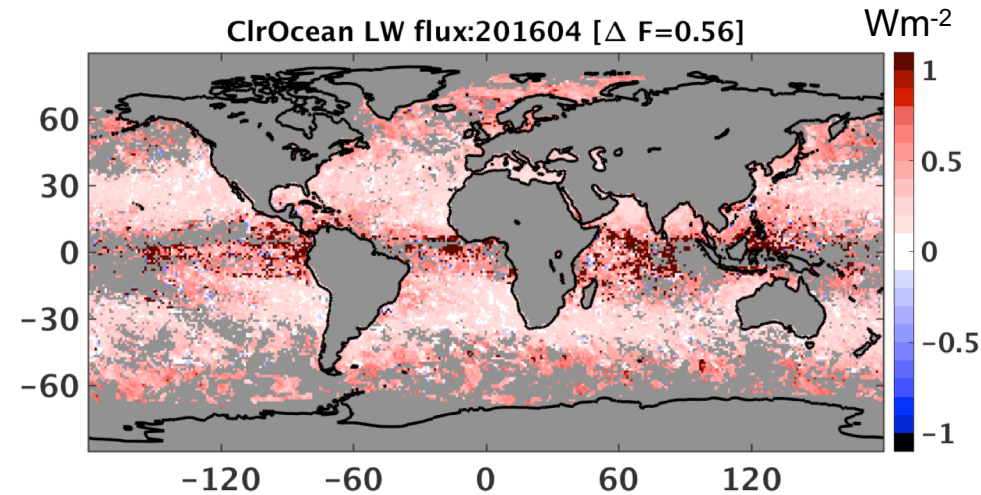


Daytime LW flux difference over clear ocean

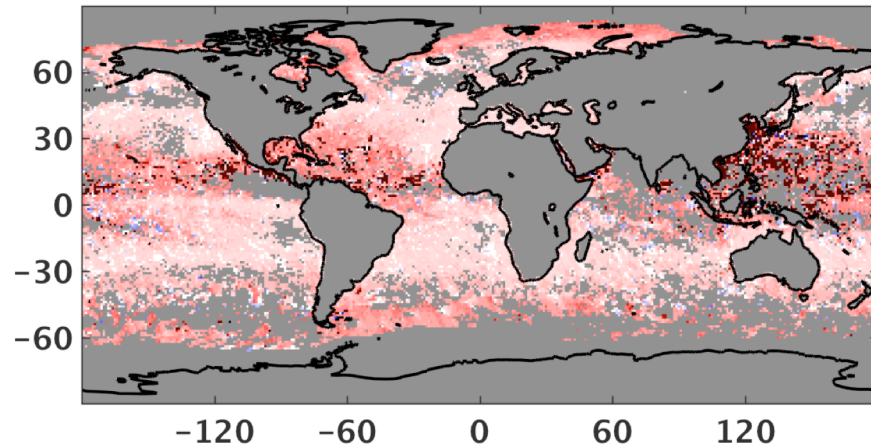
ClrOcean LW flux:201601 [$\Delta F=0.46$]



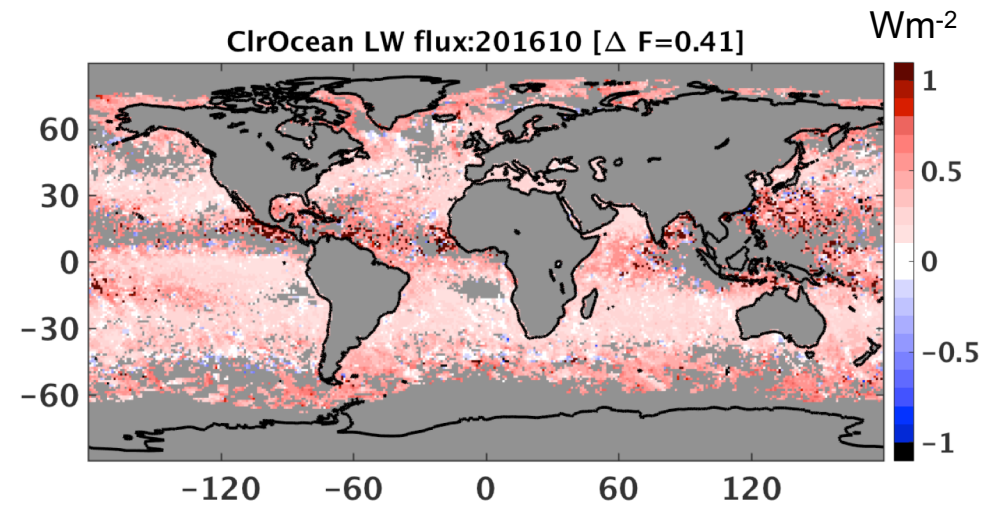
ClrOcean LW flux:201604 [$\Delta F=0.56$]



ClrOcean LW flux:201607 [$\Delta F=0.51$]

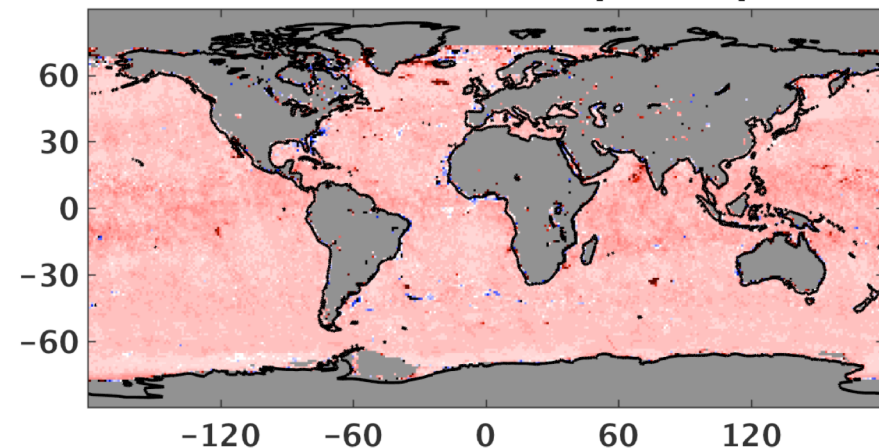


ClrOcean LW flux:201610 [$\Delta F=0.41$]

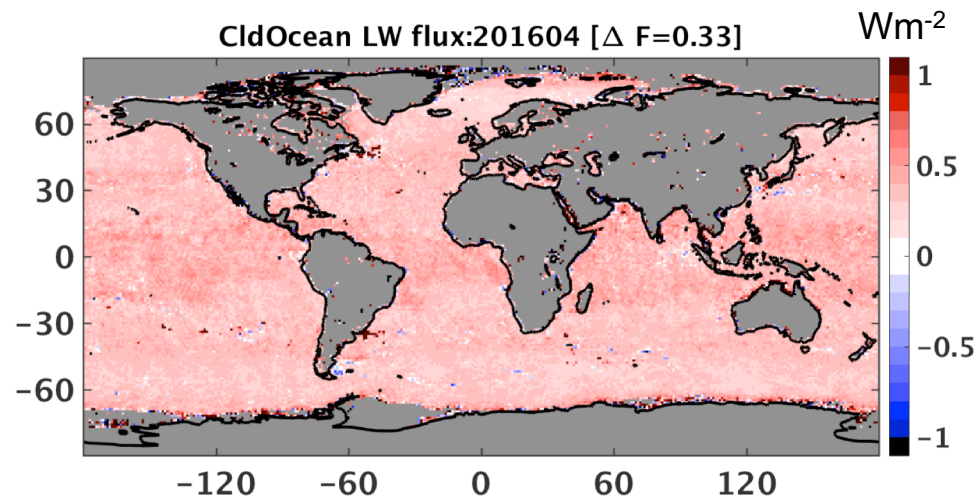


Daytime LW flux difference over cloudy ocean

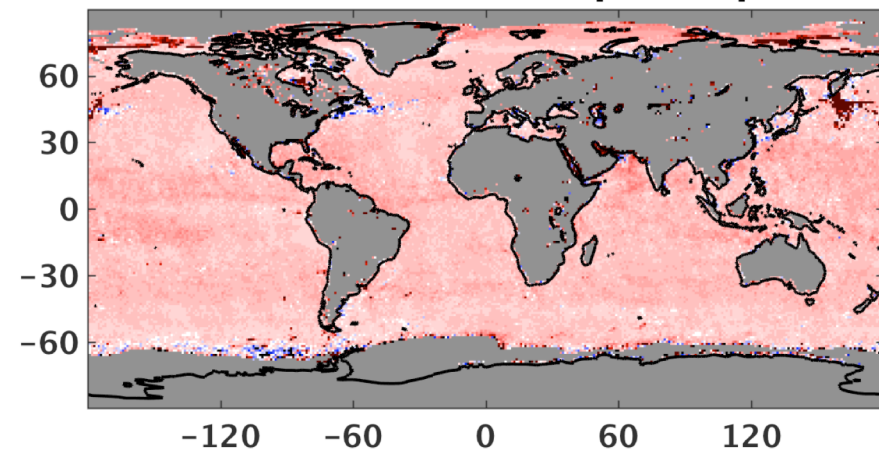
CldOcean LW flux:201601 [$\Delta F=0.32$]



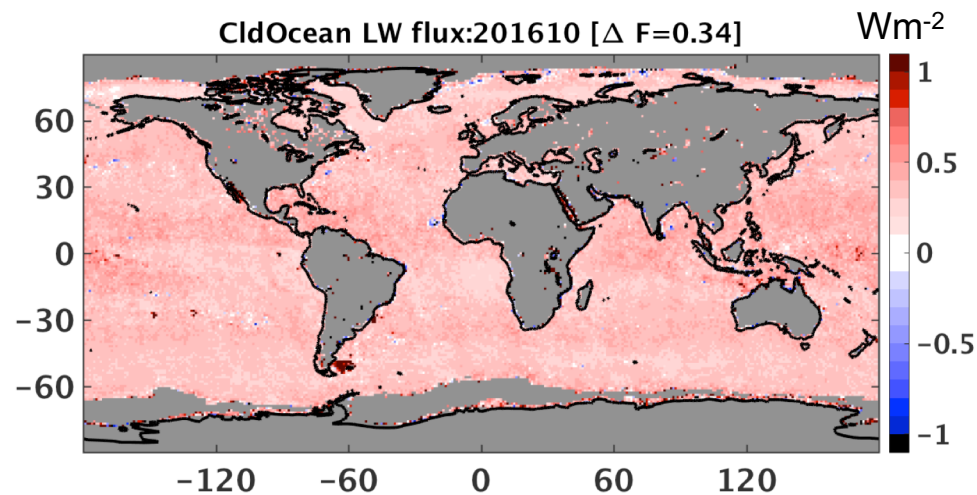
CldOcean LW flux:201604 [$\Delta F=0.33$]



CldOcean LW flux:201607 [$\Delta F=0.33$]

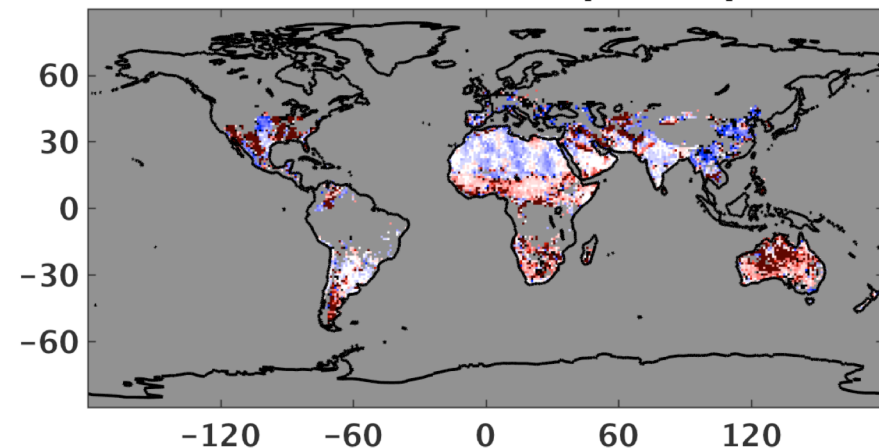


CldOcean LW flux:201610 [$\Delta F=0.34$]

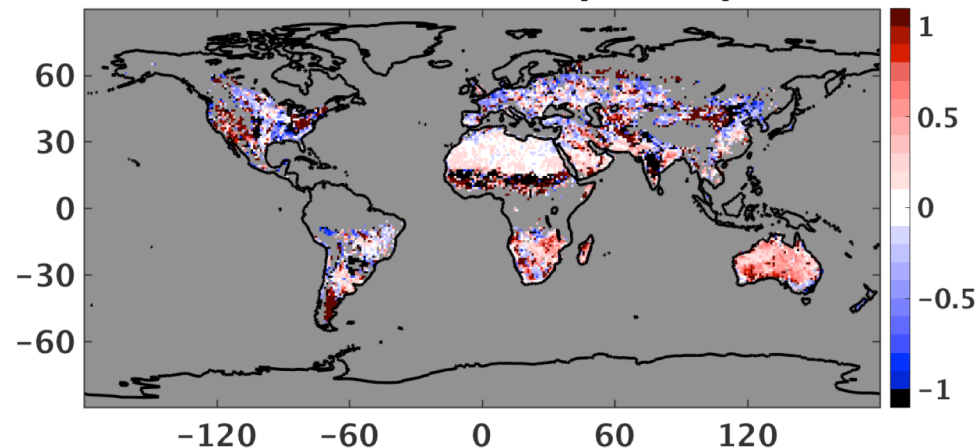


Daytime LW flux difference over clear land

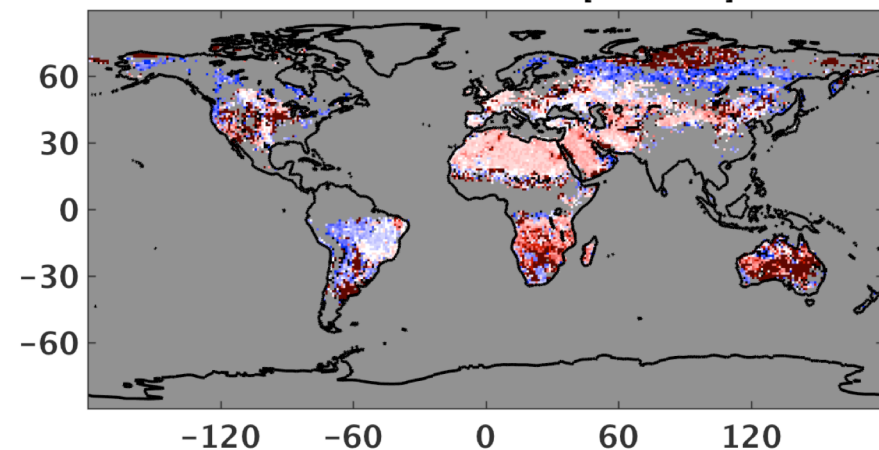
ClrLand LW flux:201601 [$\Delta F=0.53$]



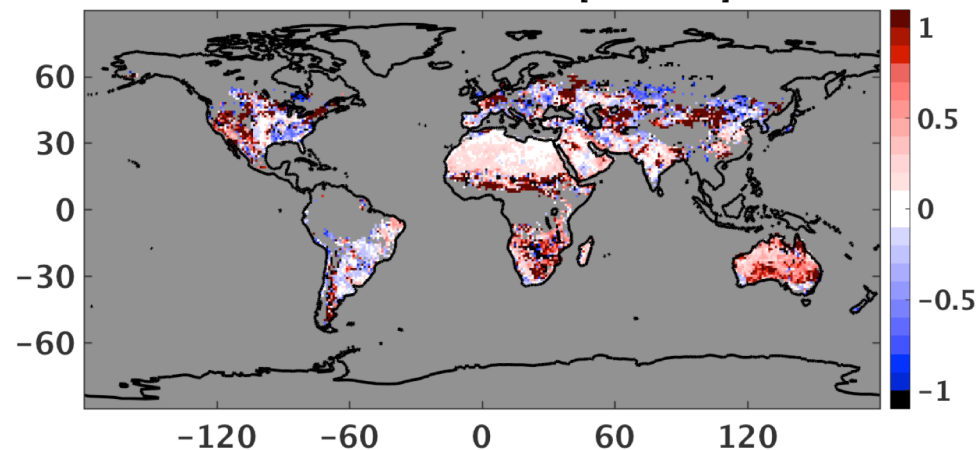
ClrLand LW flux:201604 [$\Delta F=0.07$]



ClrLand LW flux:201607 [$\Delta F=0.47$]

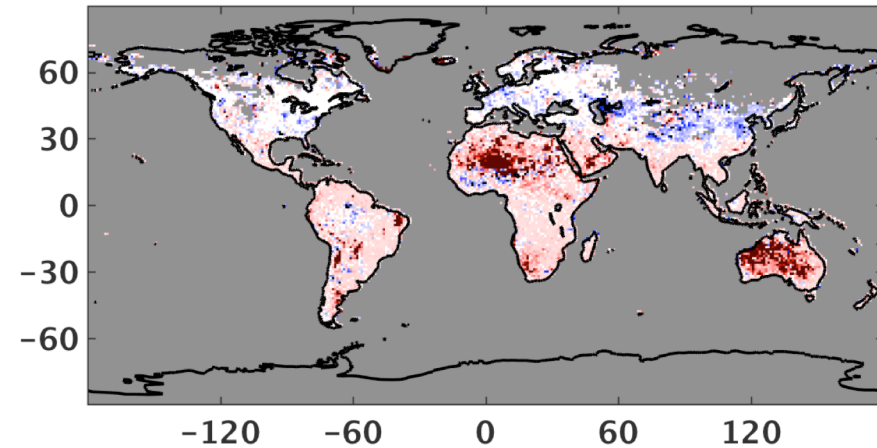


ClrLand LW flux:201610 [$\Delta F=0.64$]

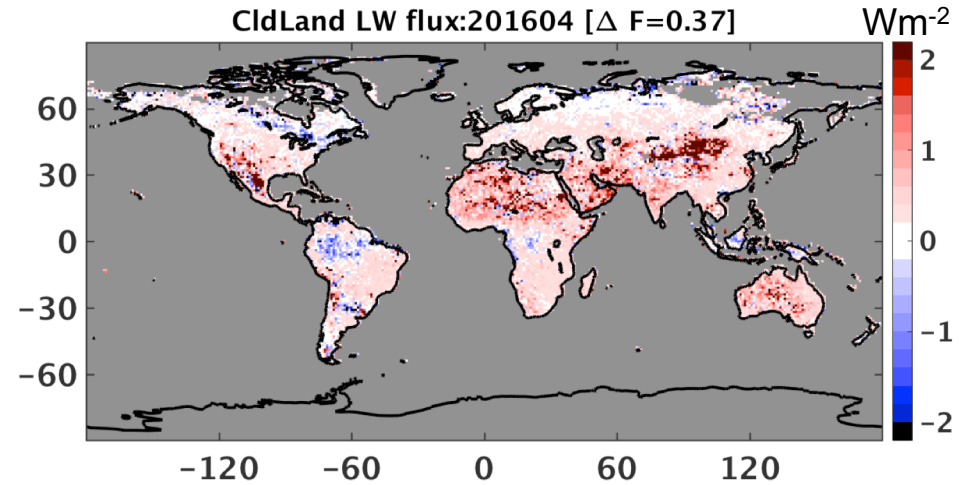


Daytime LW flux difference over cloudy land

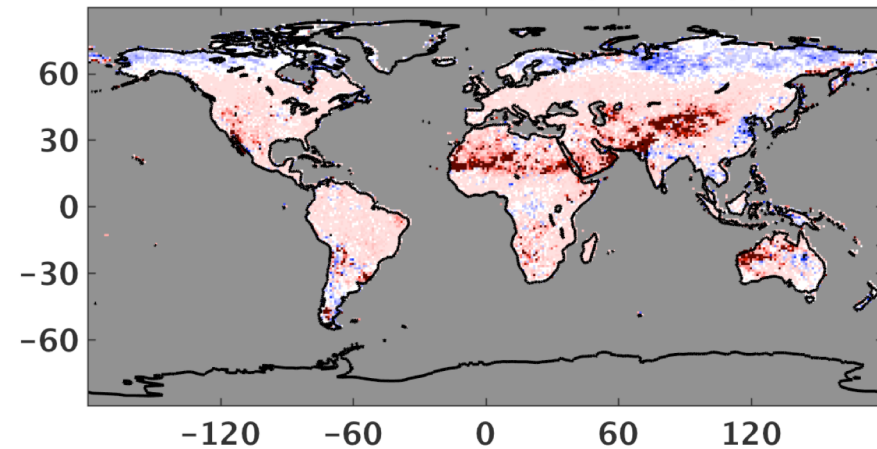
CldLand LW flux:201601 [$\Delta F=0.34$]



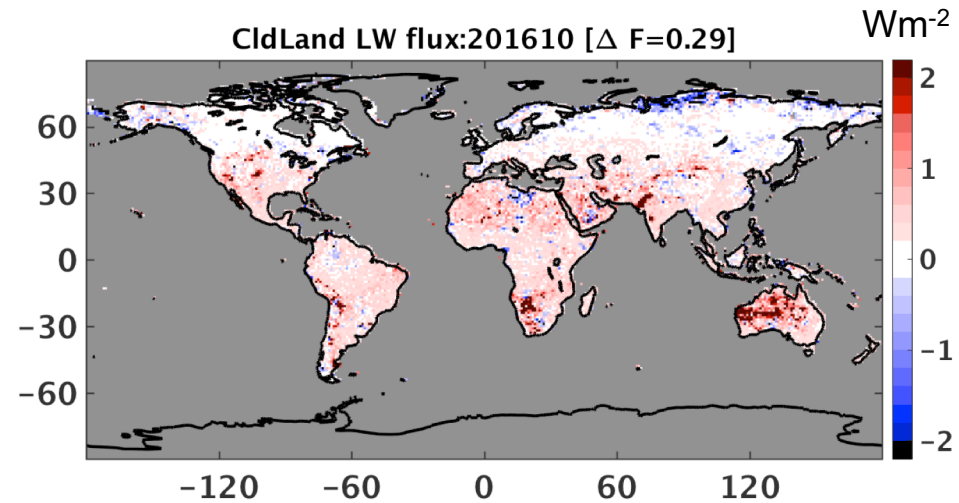
CldLand LW flux:201604 [$\Delta F=0.37$]



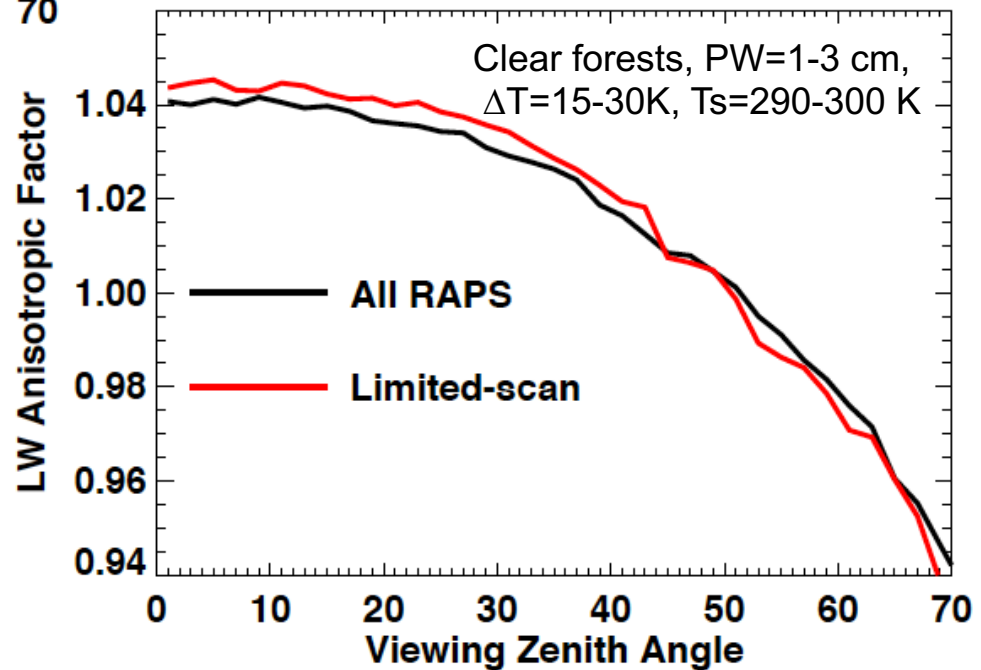
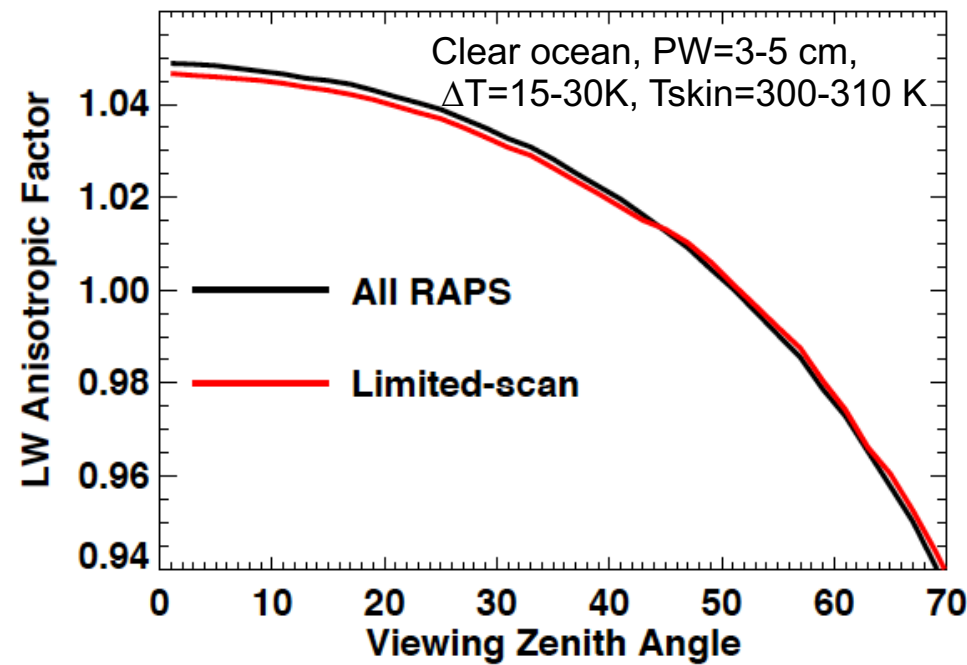
CldLand LW flux:201607 [$\Delta F=0.37$]



CldLand LW flux:201610 [$\Delta F=0.29$]



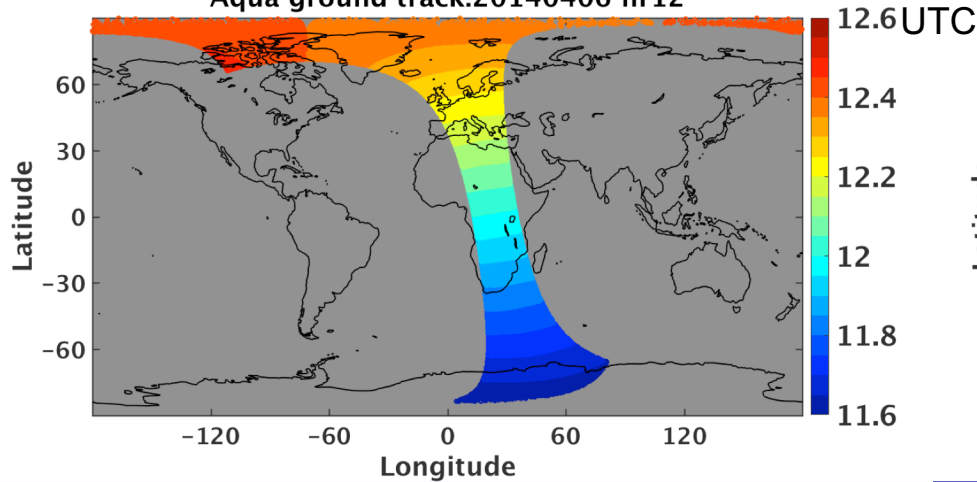
LW anisotropic factor comparison



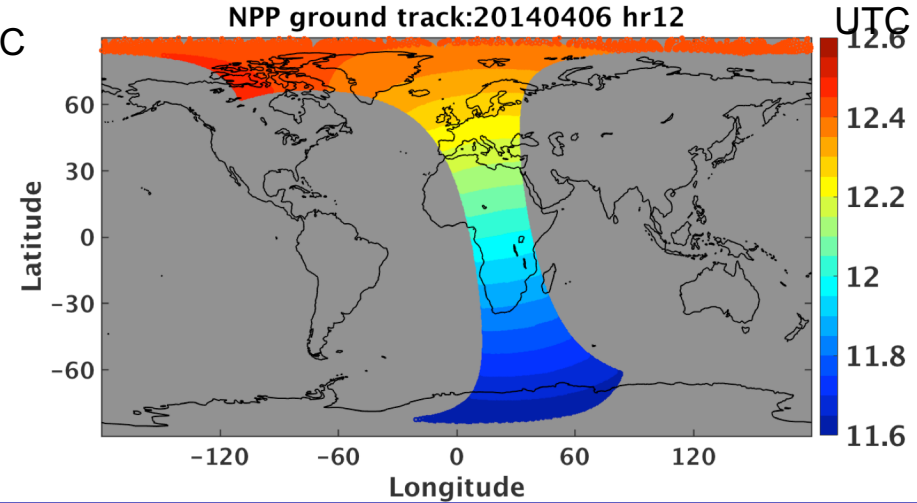
Simultaneous observations of Aqua and NPP: ~every 64 hours, Aqua and Suomi-NPP fly "in tandem"

Time of observations when Aqua and NPP fly in tandem

Aqua ground track:20140406 hr12

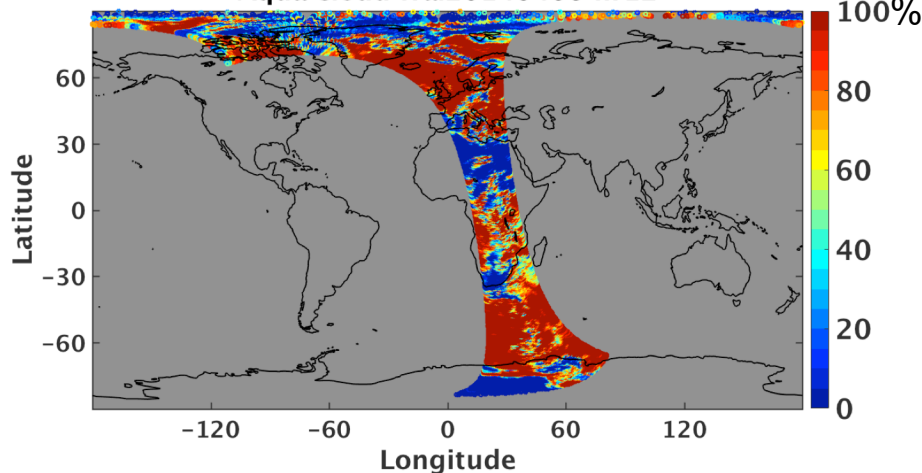


NPP ground track:20140406 hr12

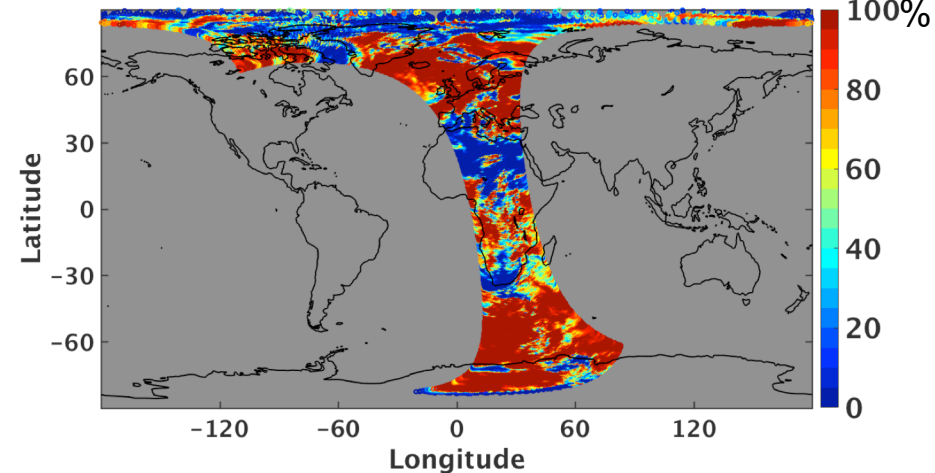


Cloud fraction retrievals for Aqua and NPP

Aqua cloud fra:20140406 hr12



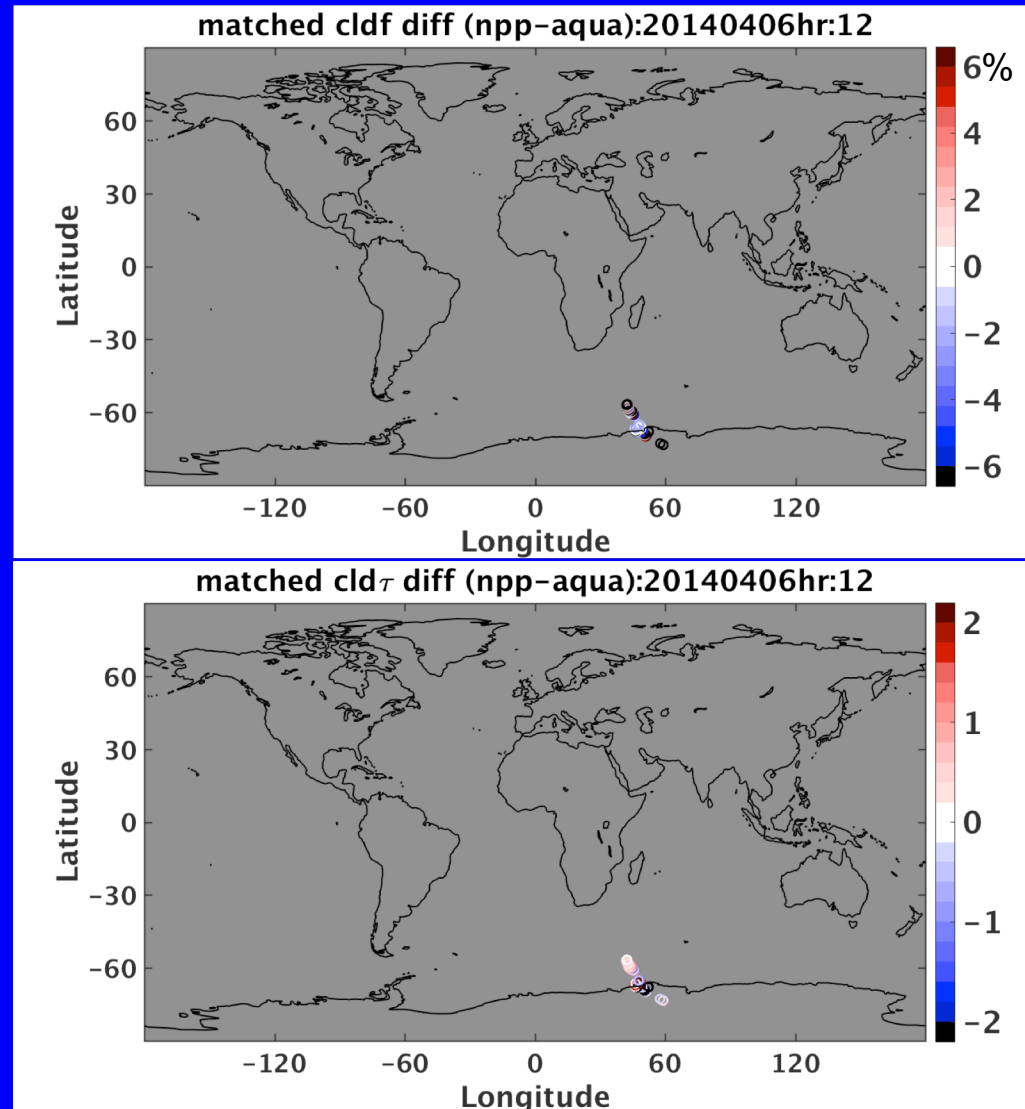
NPP cloud fra:20140406 hr12



Cloud property consistency between Aqua and NPP

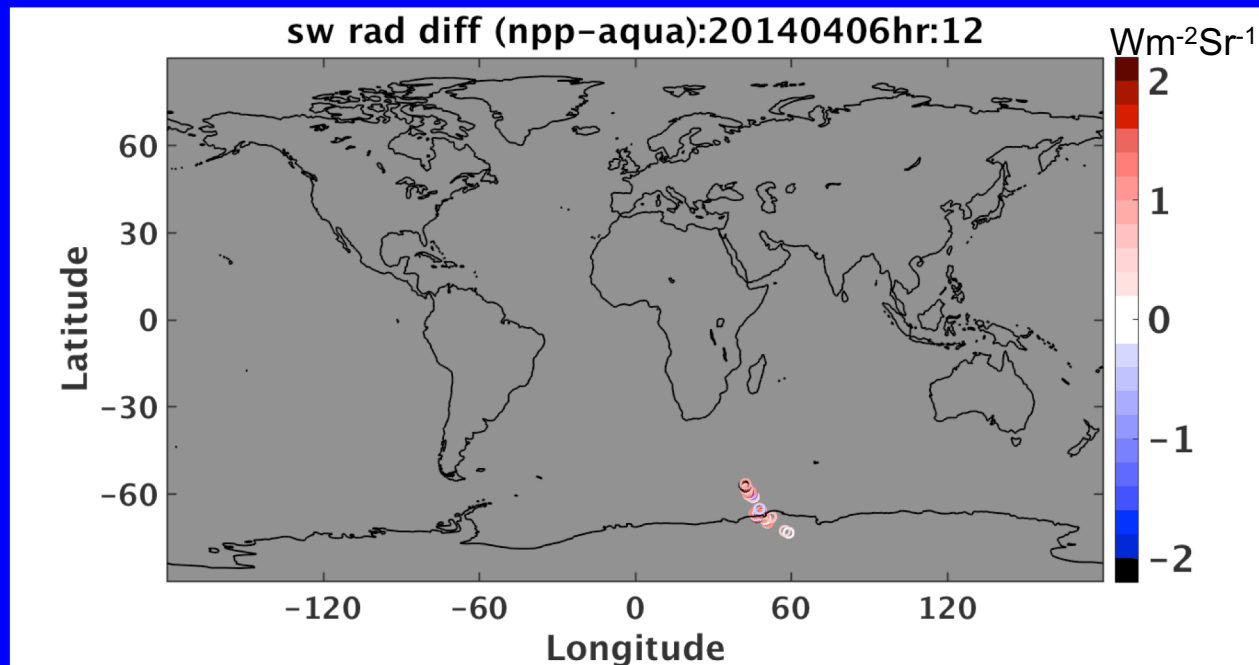
- These simultaneous observations from Aqua and Suomi-NPP are matched to compare cloud fraction (f) and cloud optical depth (τ) using only observations taking at $VZA < 10^\circ$.
- Matching criteria are:
 - latitude and longitude differences are less than 0.05 degree, solar zenith angle and viewing zenith angle differences are less than 2 degrees, relative azimuth angle difference is less than 5 degrees.

Only 59 matched footprints



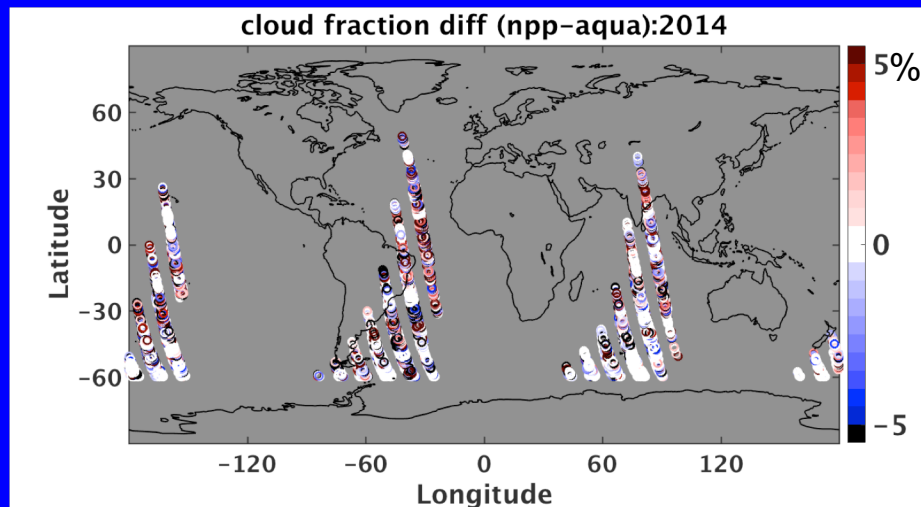
Minimize the effect of calibration difference on flux comparison

- Ed1 NPP and Ed4 Aqua are not on the same radiometric scale
- To minimize the effect of calibration difference on flux comparison, the NPP radiances are scaled to be the same as the Aqua radiances
- All results are based upon the matched daytime footprints of 2014

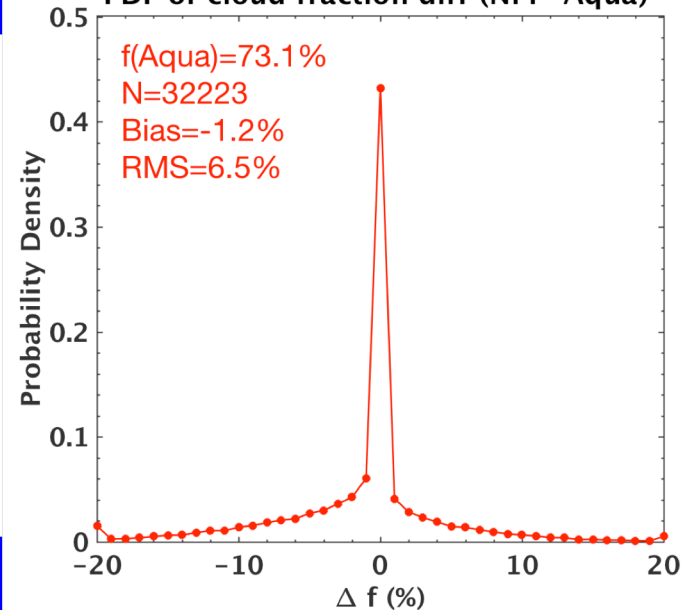


Cloud property difference for matched footprints over 60°S-60°N

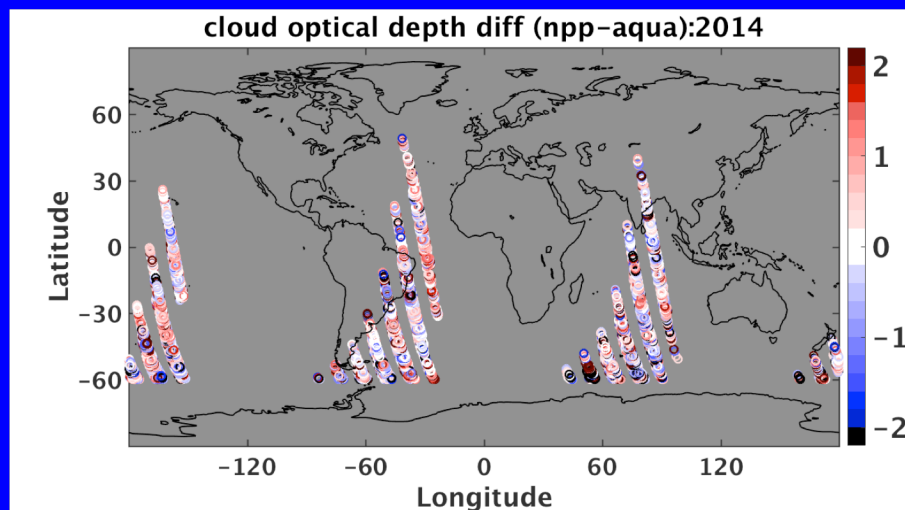
Cloud
fraction



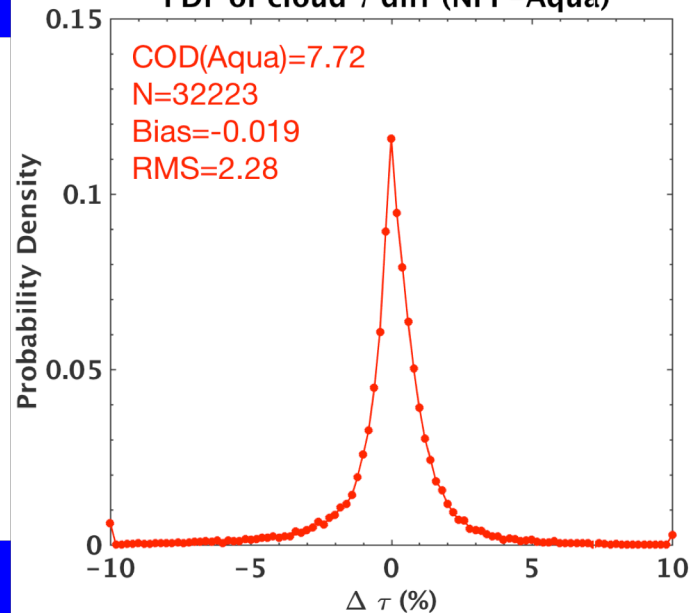
PDF of cloud fraction diff (NPP-Aqua)



Cloud
optical
depth

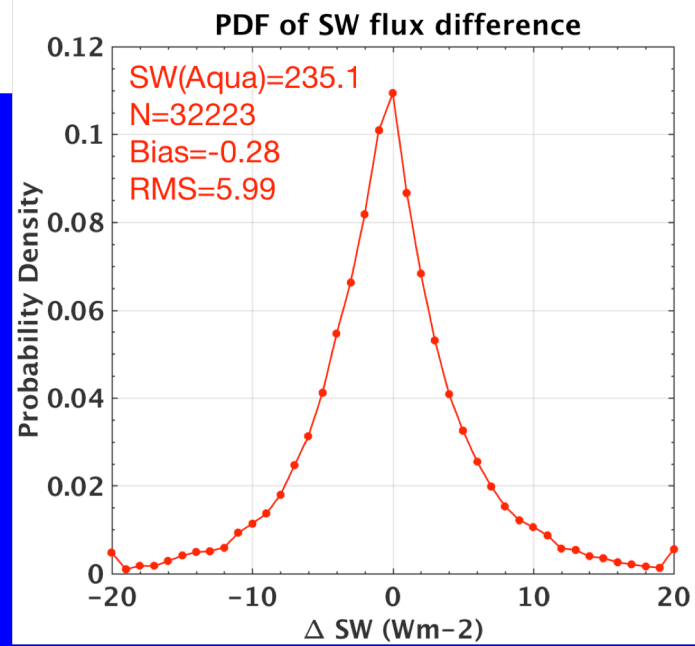
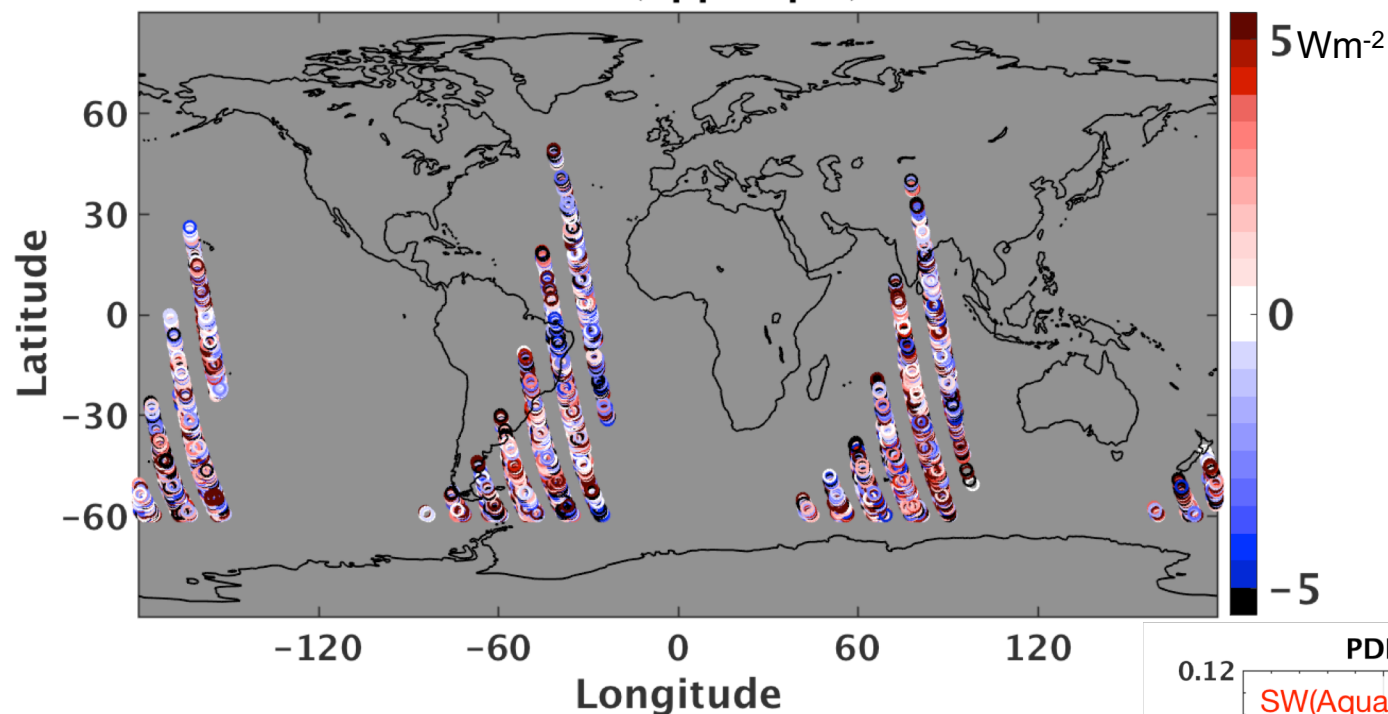


PDF of cloud τ diff (NPP-Aqua)

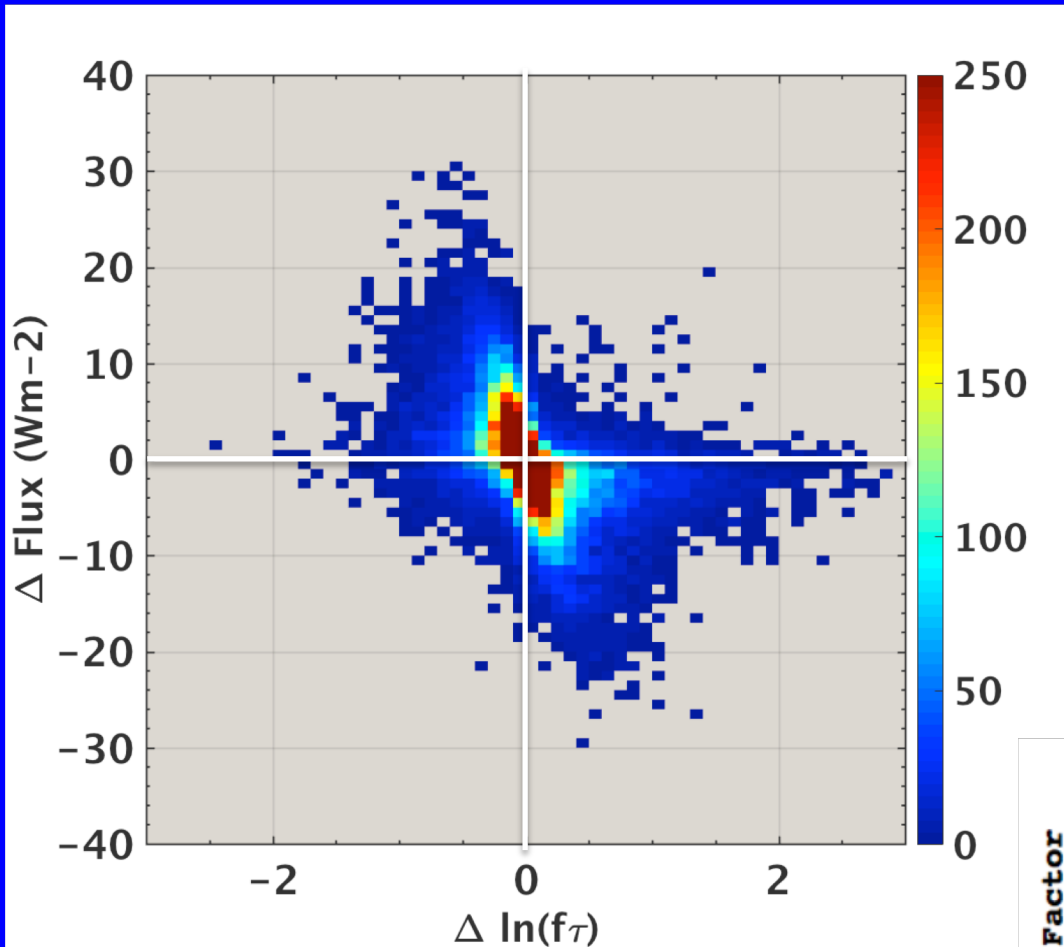


SW flux difference for matched footprints over 60°S-60°N

SW flux diff (npp-aqua):2014



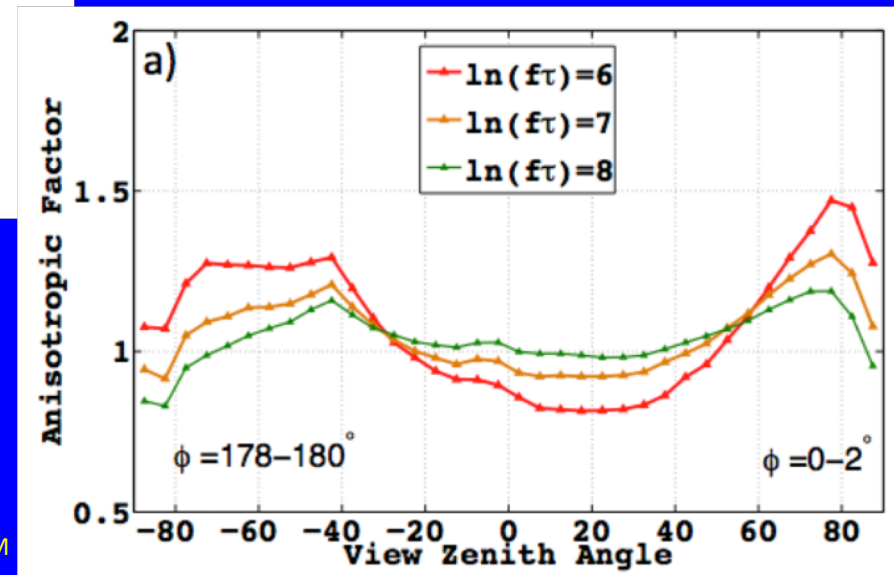
SW flux difference vs. $\ln(f\tau)$ difference over 60°S-60°N



- If $\ln(f\tau)$ from NPP is smaller than that from Aqua, the anisotropic factor derived using NPP scene id is smaller than that derived using Aqua scene id
- The inverted NPP flux is thus greater than the Aqua flux based upon their individual scene id

* Δ = NPP-Aqua

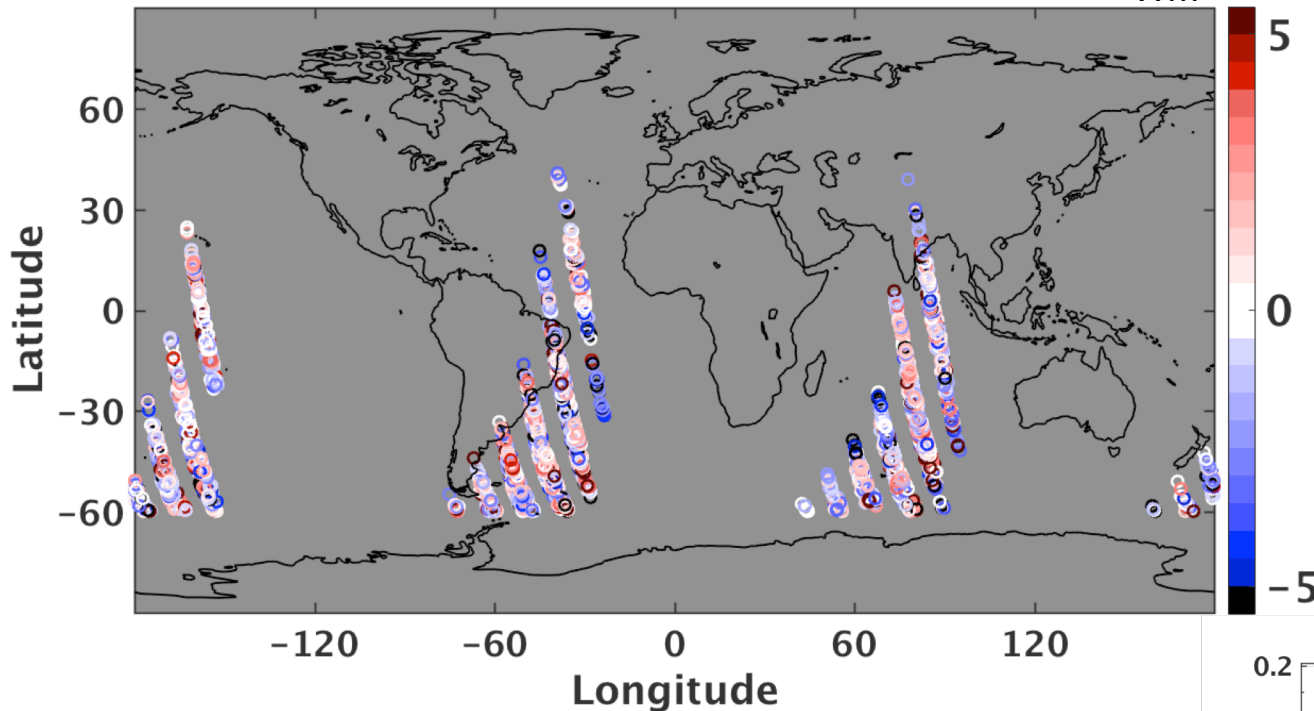
$$F = \frac{\pi I}{R}$$



SW flux difference for matched footprints with $\Delta f < 2\%$ and $\Delta \tau < 0.2$ over $60^\circ\text{S}-60^\circ\text{N}$

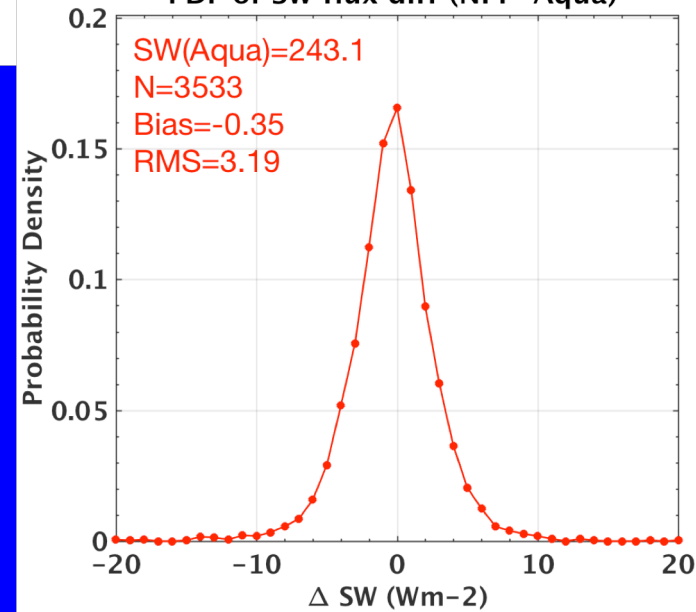
SW flux diff (npp-aqua):2014

Wm^{-2}



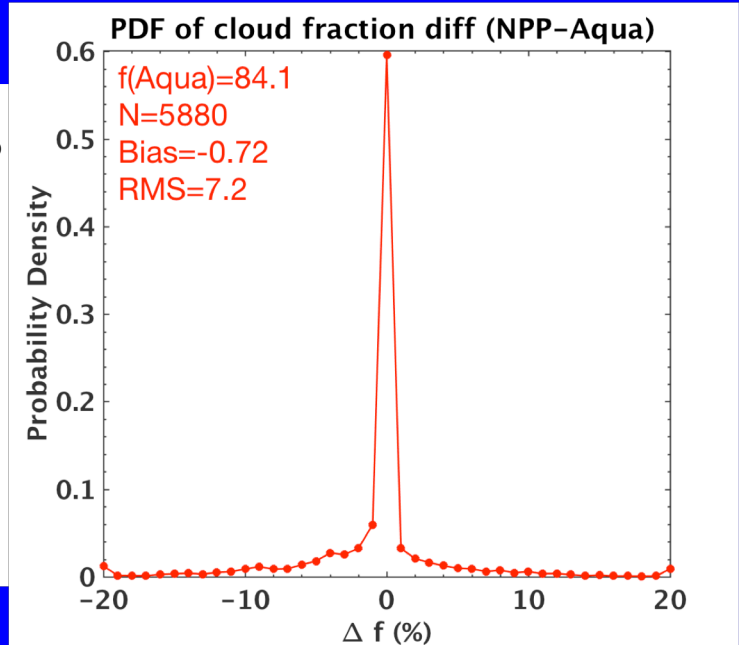
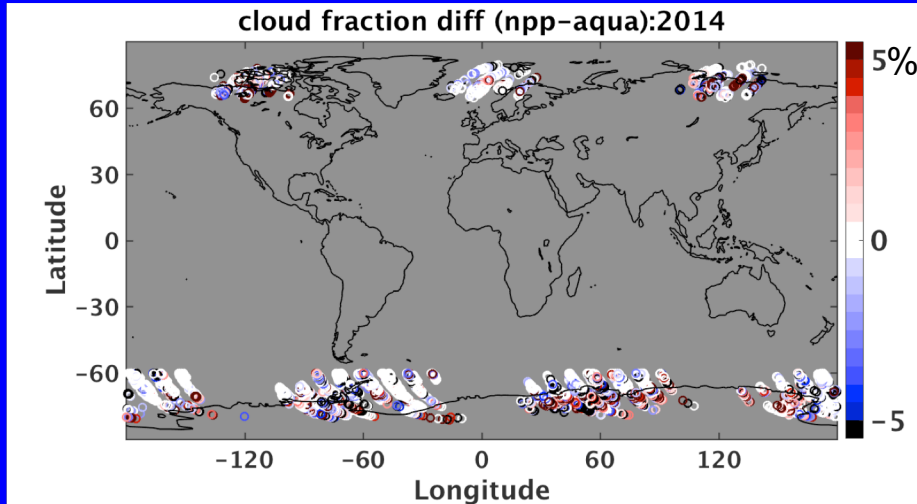
- Only about 10% of the matched footprints have small cloud fraction and optical depth difference;
- When cloud f/τ agree, the RMS error is reduced by 50%.

PDF of SW flux diff (NPP-Aqua)

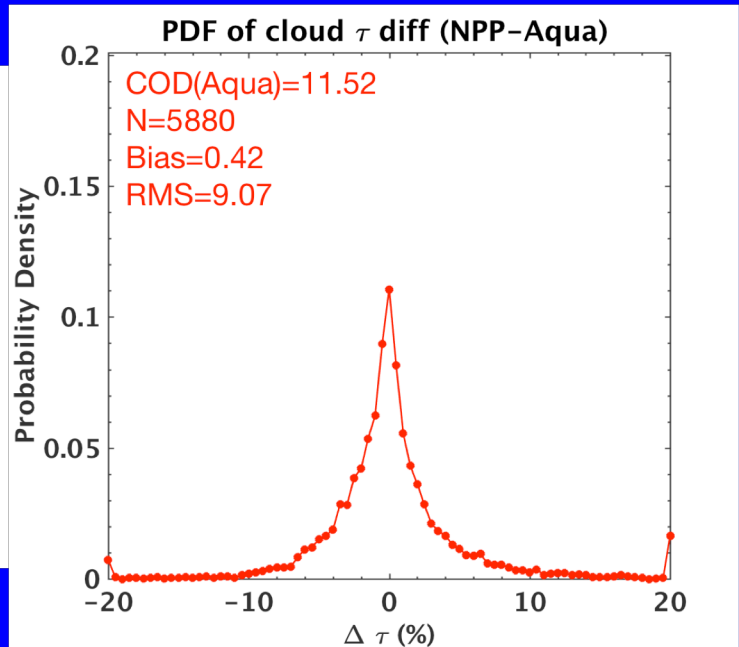
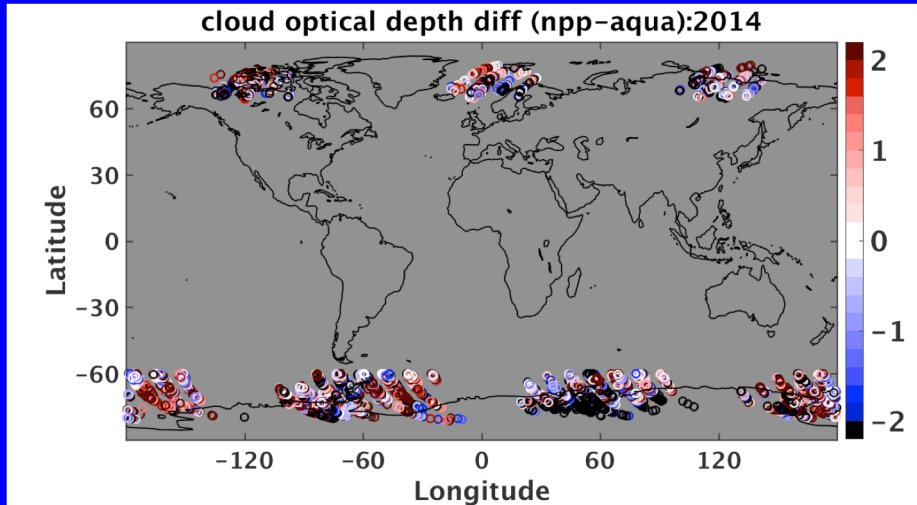


Cloud property difference for matched footprints poleward of 60°

Cloud
fraction

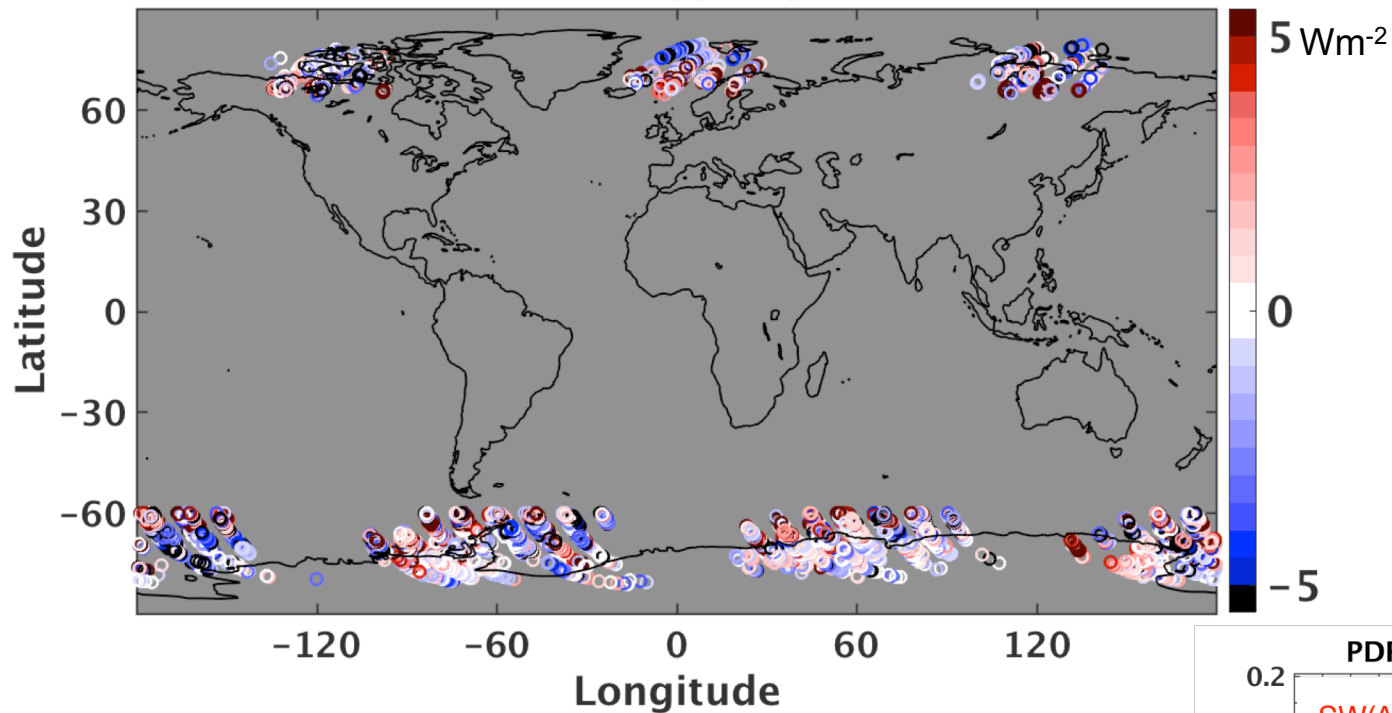


Cloud
optical
depth

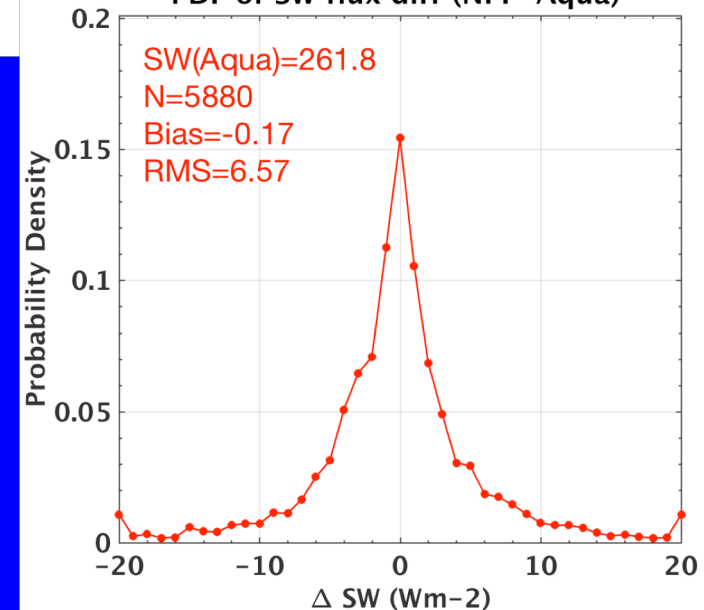


SW flux difference for matched footprints poleward of 60°

SW flux diff (npp-aqua):2014

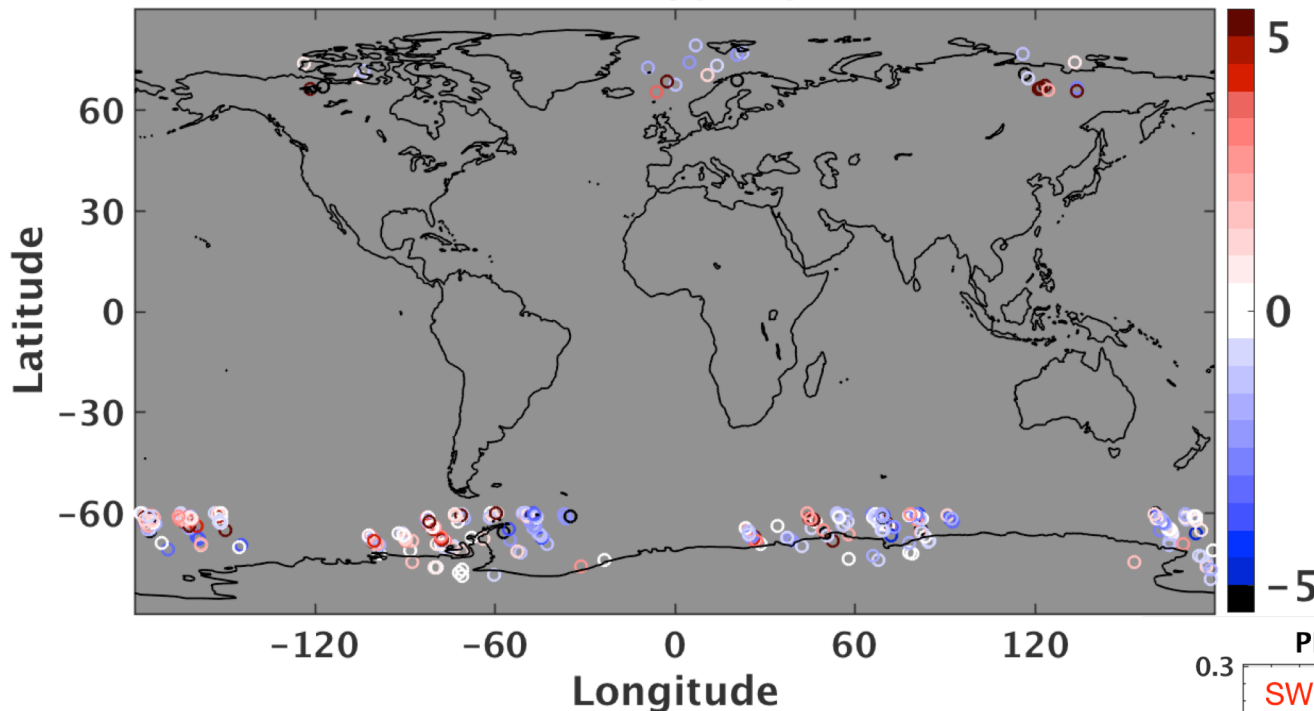


PDF of SW flux diff (NPP-Aqua)



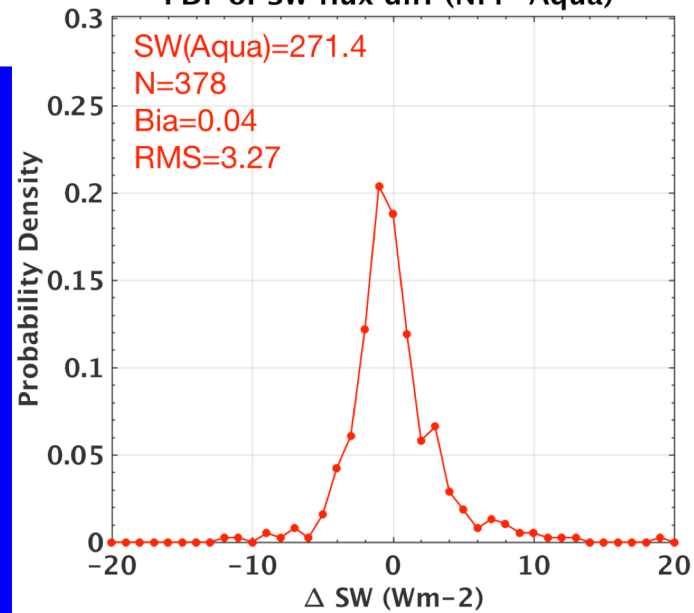
SW flux difference for matched footprints poleward of 60° with $\Delta f < 2\%$ and $\Delta \tau < 0.2$

SW flux diff (npp-aqua):2014



- Only about 6.5% of the matched footprints have small cloud fraction and optical depth difference;
- When cloud f/τ agree, the RMS error is reduce by about 50%;

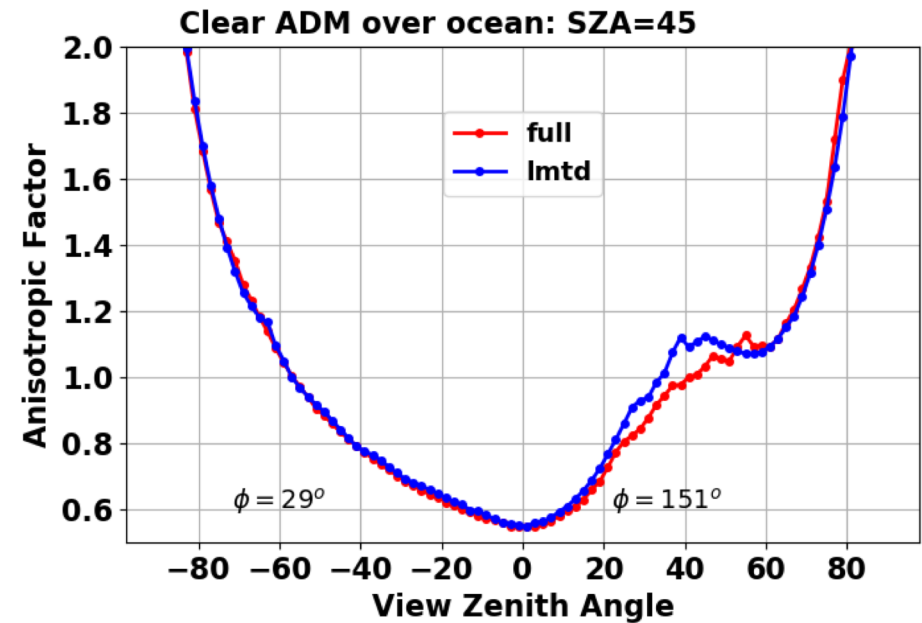
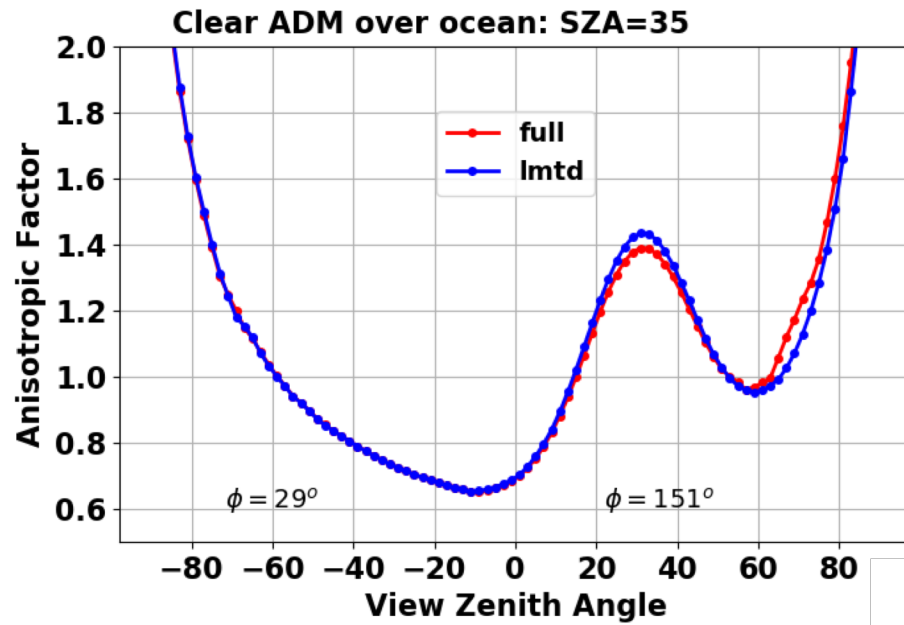
PDF of SW flux diff (NPP-Aqua)



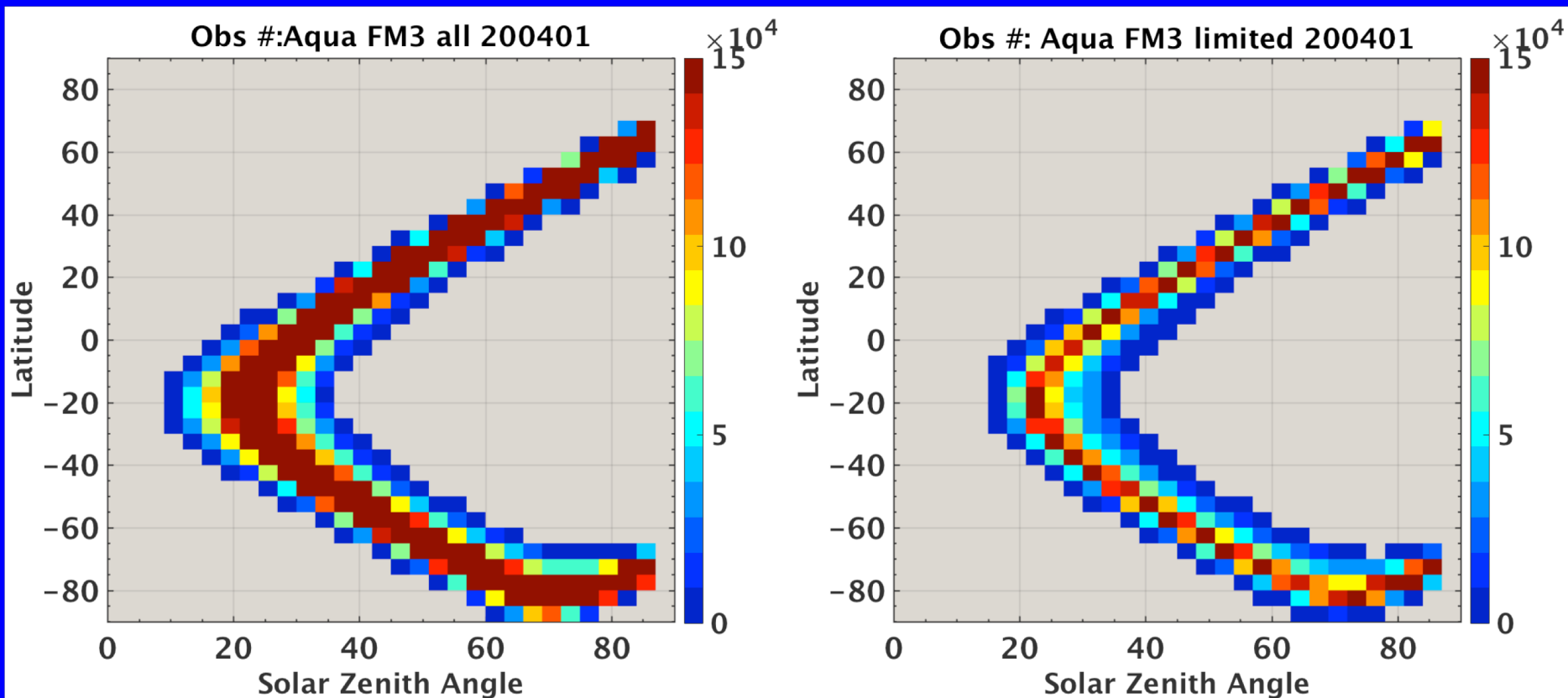
Summary

- CERES on NPP can only be placed in limited Sun exposure scan mode. This limited scan mode only provides about 1/3 of the measurements comparing to the full RAPS mode
- Fluxes inverted using ADMs developed with the limited RAPS are compared with fluxes inverted using ADMs developed with the full RAPS
 - Monthly mean instantaneous SW flux differences over ocean are small, but large biases are observed over land
 - Monthly mean daytime LW flux differences are all positive over ocean, and larger differences are observed over land
- Matched NPP and Aqua nadir footprints are used to investigate cloud property differences on SW flux inversion
 - RMS error is reduced by ~50% when only consider footprints with small cloud fraction ($<2\%$) and cloud optical depth (<0.2) differences.

SW anisotropic factor comparison over clear ocean



Limited scan reduced number of footprints in RAPS mode by ~67%



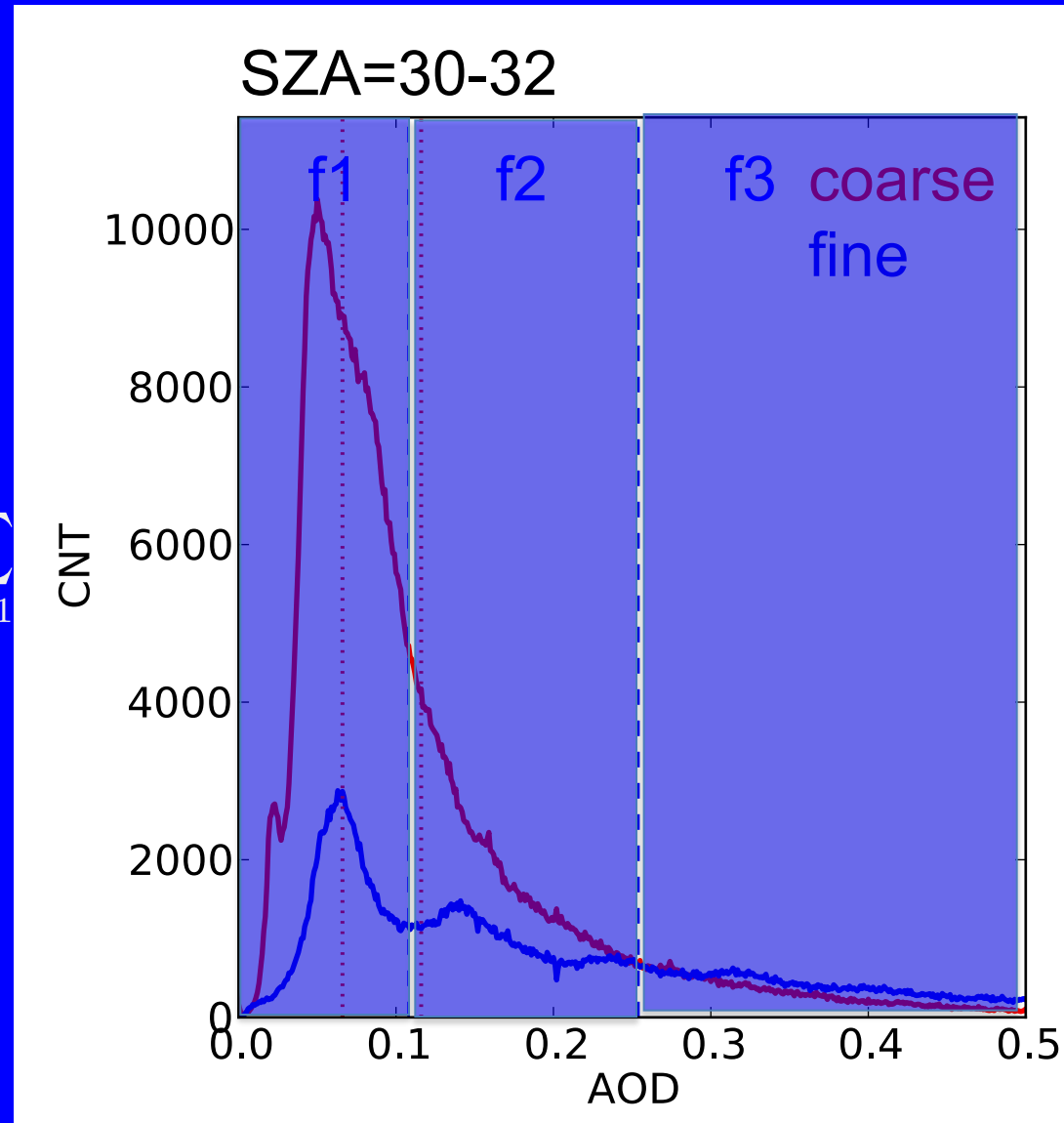
Ed4ADM over clear ocean accounts for aerosol loading and type

- AOD retrieval based upon a fine-mode aerosol look-up table (urban) and a coarse-mode aerosol look up table (maritime);

- Stratify fine-mode aerosols into 3 AOD bins and coarse-mode aerosols into 3 AOD bins;

$$\epsilon_c = \sum_{j=1}^6$$

- Build ADM for each AOD bin and type separately (6 ADMs).



Angular distribution model over clear land

- Collect clear-sky CERES reflectance over $1^\circ \times 1^\circ$ regions for each month;
- Stratify reflectance within each $1^\circ \times 1^\circ$ region by NDVI (0.1) and $\cos\theta_0$ (0.2);
- Apply a modified RossLi fit to produce BRDF and ADM for each NDVI and $\cos\theta_0$ intervals within each $1^\circ \times 1^\circ$ region.
 - B1 estimates the directional reflectance of a flat surface with randomly distributed and oriented protrusions;
 - B2 approximates the radiative transfer within a vegetation canopy, accounts for the hot spot effect;

$$\rho(\mu_0, \mu, \phi) = k_0 + k_1 \cdot B_1(\mu_0, \mu, \phi) + k_2 \cdot B_2(\mu_0, \mu, \phi)$$

Angular distribution model over cloudy ocean

- For glint angle $> 20^\circ$, or glint angle $< 20^\circ$ and $\ln(f\tau) > 6$:
 - Average instantaneous radiances into 775 intervals of $\ln(f\tau)$ for each angular bin (2°) separately for liquid, mixed, and ice clouds;
 - Apply a five-parameter sigmoidal fit to mean radiance and $\ln(f\tau)$:

$$I = I_0 + \frac{a}{[1 + e^{-(x-x_0)/b}]^c}$$

- For glint angle $< 20^\circ$ and $\ln(f\tau) < 6$:
 - Calculate mean radiance for 6 wind speed bins and 4 $\ln(f\tau)$ bins;
 - Use mean radiance to build ADM

Angular distribution model over cloudy land

- Use land clear to calculate ρ^{clr} ;
- Use lookup table (17 SZA and 19 COD) to calculate the scattering by the surface and atmosphere transmitted through the clouds;

$$fI^{cld}(\mu_0, \mu, \phi) = I(\mu_0, \mu, \phi) - (1 - f) \frac{\mu_0 E_0}{\pi} \rho^{clr}(\mu_0, \mu, \phi) -$$

$$f \frac{\mu_0 E_0}{\pi} \left[\rho^{clr}(\mu_0, \mu, \phi) e^{-\pi/\mu_0} e^{-\pi/\mu} + \bar{\alpha}^{clr} \frac{t^{cld}(\tau, \mu_0) t^{cld}(\tau, \mu)}{1 - \bar{\alpha}^{clr} \bar{\alpha}^{cld}(\tau)} \right]$$

- Bin instantaneous fI^{cld} into 380 $\ln(f\tau)$ bins;
- Calculate the mean fI^{cld} for each $\ln(f\tau)$ bin;
- Apply a five-parameter sigmoidal fit to mean fI^{cld} and $\ln(f\tau)$

$$I = I_0 + \frac{a}{[1 + e^{-(x-x_0)/b}]^c}$$